Impacts of climate change on rural water infrastructure

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Authors: B Kouvelis, C Scott, E Rudkin, D Cameron, M Harkness, A Renata, G Williams

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Publisher

Ministry of Agriculture and Forestry
PO Box 2526
Pastoral House, 25 The Terrace
Wellington 6140
www.maf.govt.nz

Telephone: 0800 008 333

Facsimile: +64 4 894 0300

REPORT

Impacts of Climate Change on Rural Water Infrastructure

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QUALITY ASSURANCE STATEMENT

PROJECT MANAGER	REVIEWED BY
Emily Rudkin	Bruce Trangmar
PREPARED BY	**APPROVED FOR ISSUE BY**
Brian Kouvelis, Craig Scott, Emily Rudkin, Dave Cameron, Mike Harkness, Alayna Renata, Gary Williams	Emily Rudkin

CHRISTCHURCH
Hazeldean Business Park, 6 Hazeldean Road, Addington, Christchurch 8024
PO Box 13-249, Armagh, Christchurch 8141
TEL +64 3 366 7449, FAX +64 3 366 7780

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MAF

Impacts of Climate Change on Rural Water Infrastructure

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Executive Summary

This project has identified a range of impacts that arise from a changing climate that affect rural water infrastructure. Climate change will impact on both the performance and long term operations of irrigation schemes and rural water supply schemes.

To assess the climate change impacts on New Zealand's rural water infrastructure, five case studies were selected for the irrigation scheme assessment and seven schemes for the assessment of rural stockwater supply schemes. The schemes were selected to cover a range of geographic climatic variations, catchment hydrology and infrastructure assets. They were located in varying regions of New Zealand, from Northland to Southland. The irrigation scheme case studies comprised old and new schemes, with both pipe and canal distribution, with various storage sizes from small to large, irrigating between 2,000 to 18,000 hectares. The rural stock water supply schemes comprised different scheme types, from constant flow to on-demand schemes and operating via pumped and gravity feed, serving between 200 to 20,000 hectares. The case study schemes selected were:

	Scheme	Area	Size (ha)
Irrigation Schemes	Kerikeri Irrigation Company	Northland	2,800
	Tablelands Irrigation Scheme	Bay of Plenty	300
	Southern Valleys Irrigation Scheme	Marlborough	4,500
	Waimakariri Irrigation Scheme	Canterbury	18,000
	Manuherikia Irrigation Scheme	Central Otago	2,245
Rural Stock Water Supply Schemes	Cold Creek RWS	Taranaki	7,623
	Hunterville RWS	Rangitikei	10,000
	Wainuiouru RWS	Wairarapa	20,000
	Redwoods Valley RWS	Tasman	2,500
	Malvern Plains RWS	Canterbury	200
	Rocklands RWS	Otago	1,500
	Homestead	Southland	2,200

An assessment of the meteorological and hydrological changes and consequential changes to water quality and ecology was conducted for each of the case study regions. This referred to existing climate change projections, including the statistically downscaled version of the IPCC Fourth Assessment Report to show climate change effects for New Zealand. This assessment showed:

- A fairly uniform pattern of warming across New Zealand, with an average increase of about 0.9°C by 2040 and 2°C by 2090.
- Average annual rainfalls are expected to increase in most areas, with the exception of the far north of the North Island and the east coast. There are some seasonal changes, with reduced summer rainfall in the upper catchments of the Southern Alps and reduced spring rainfall in Northland.
- Extreme heavy rainfall is projected to increase in magnitude and/or frequency across the entire country.
- Similarly, the frequency of drought events is projected to increase nationwide.
- The occurrence of days with temperature in excess of 25°C is projected to increase, with the greatest increase in the north and the least increase in the south.
- Warmer water temperatures could lead to increased risk of new invasive organisms in source streams, reservoirs or distribution races.
- Warmer water temperatures and increased carbon dioxide levels could lead to increased aquatic plant productivity in source streams, with increasingly variable pH and dissolved oxygen regimes and increased algae biomass.

Details on each of these case study schemes were sourced, including investigation and design reports, scheme plans and photos. The components of the rural water infrastructure were determined

and formed the basis for identification and discussion of the impacts due to climate change. Interviews were held with the managers of the irrigation schemes to identify their opinions on the likely impacts of climate change on their schemes. An economic assessment was carried out for each scheme which included assessment of the impact of climate change on operation and maintenance budgets.

The climate change effects identified for the case study schemes is summarised below.

Climate Change	Effect
Increase in rainfall	Higher rainfall and average river and stream flows will provide benefits for instream ecology and at times reduce pressure on the water resource.
Decrease in rainfall	Lower stream flows and potentially more rigorous residual flow requirements for source streams. Increased pressure on water resources.
Changing rainfall patterns	Seasonal variations may lead to increased pressure on water resources at times. Less water (or more water) available for storage at different times of the year.
Less snow fall and shorter snow melt season	Lower flows in spring and summer may lead to increased pressure on water resources at times.
Increased risk of drought	Increased frequency and durations of very low river and stream flows may at times increase pressure on water resources and stream ecology. Minimum/environmental flow could be reached more often and abstraction for schemes reduced or halted for periods of time.
Increase in average temperature; Increase in very hot days	Increased temperatures in source rivers and streams with potentially adverse effects on stream ecology. Increased temperatures in storages contributing to higher risk of nuisance algae blooms. Increased risk of weeds, pest fish or other unwanted organisms. May contribute to increased variability on DO and pH regimes. Potentially higher maintenance costs for scheme infrastructure due to clogging of screens and increased corrosion. May also increase the risk of invasion by other unwanted organisms (but possibly reduced risk associated with didymo). Increase in peak demand for stock watering.
Increased frequency of heavy rain events	Increased sediment and nutrient inputs to storages contributing to higher risk of nuisance algae blooms or weeds. Increased sediment yields and erosion in scheme catchments. Potentially increased maintenance costs for scheme infrastructure. An increase in the frequency of large floods may lead to re-evaluation of design parameters for storage lakes. Potential effects on pipeline stability.
Increased summer water deficit for un-irrigated land	Increased water demand for land currently in schemes.
Increased windiness	Coupled with an increase in temperature this could lead to an increase in erosion of topsoil.
Sea level rise	Bores near the coast will have an increased risk of saltwater intrusion.
Decrease in groundwater levels	Increase in pumping head.

Climate change will impact on all rural water infrastructure schemes to a greater or lesser extent across all the New Zealand climatic regions. The project has also shown that climate change will impact on all the infrastructure components of rural water schemes, affecting capital, operating and maintenance costs. The overall implications of climate change from an infrastructure perspective are shown from the case studies to be inversely proportional to size. The smaller the scheme, the greater the potential capital, operating and maintenance cost impacts.

The susceptibility to climate change of various rural water infrastructure assets was assessed as part of this project. Significant one-off capital cost was limited to flood hydrological change impacts to storage reservoir spillways. The upgrade of spillways is typically very expensive. Weed growth due to water quality likely induced by warmer water temperatures was identified as an issue that would require upgrades and additional operation and maintenance costs. Many schemes have screened intakes and these will require increases in capacity and cleaning mechanisms.

Mechanical items such as pumps, gates and valves, are likely to be affected through increased sediment-induced wear and tear and increased operational use, and the reduction in lifespan and increased operation and maintenance costs.

The impacts on pipe infrastructure is anticipated as only moderate, and on canal based schemes the significant issues were identified to be increased operation costs with sediment and weed accumulation removal.

To minimise the financial costs associated with a changing climate, there are a number of remediation and adaptation measures that the industry and farmers could adopt. Possible response options are summarised below.

Climate Change	Impact	Response
Increase in droughts	· Reduced yields from existing storages · Increased peak water demand · Reduced pipe lifespan due to cracking of pipes from drought shrink	· Reduced production or requirement for increased storage · Increase in pipe repairs
Increase in flood risk	· Increased flood damages to key infrastructure intakes, pipeline crossings, etc	· Remediation measures to reduce flood damages · Increase in repairs · Increase in dam spillway capacities · Increased emergency planning and compliance costs
Increase in rainfall	· Increased peak runoff	· Increased culvert sizes · Identification of secondary flow paths
Changes in wind speed and direction	· Less stability in natural vegetation, more wind throw	· Contingency planning and changes to emergency management procedures
Increase in air temperatures	· Changes in air temperature · Changes in frost patterns	· Possible change in land use · Increase or decrease in frost protection mechanisms
Increase in stream temperatures	· Increase in weed growth · Increased clogging of rural water infrastructure screen intakes · Increased corrosion · Smothering of river beds reducing infiltration gallery intake performance	· Redesign intakes · Increased maintenance
Changing rainfall patterns	· Increased river flows · Decreased river flows · Aggradation of stream beds · Degradation of stream beds · Demand pattern changes · Seasonal variations may lead to increased pressure on water resources	· Additional water take maintenance · Additional river training · Additional dredging · River works to maintain intakes · Altered take regime
Sea level rise	· Impacts on hydraulic performance of drainage systems and drainage pumps	· More pumps · More maintenance · Less production · Remediation measures

Climate Change	Impact	Response
Groundwater yields	· Lowering or raising of groundwater levels · Potential salt water intrusion	· Change or adaptation of pumping systems · Need for alternative sources of water or shift of bore location
Weed and algae growth	· Fish screen blockage · Canal cleaning · Irrigator blockage · Damage and clogging of service lines and spray heads	· New technology for alternative screening · Additional screen cleaning and intake maintenance · Operation and maintenance
Consent limit abstraction reliability	· Increased flow · Decreased flow · Altered sedimentation patterns	· Additional take · Decreased take · Maintenance changes
Intake ability to abstract water	· Intake blockage · Intake damage · Altered river morphology · Fish screen utilisation	· Increase in maintenance or automation of screen cleaning · Increase in repairs or alternative intake technologies · Additional river training · Additional maintenance

The average annual increase in operation and maintenance costs for the irrigation schemes was about $20/ha, and for rural stock water supply schemes the average increase was about $5/ha. These costs are very approximate but represent a small proportion of farm gross revenues and costs.

The most significant water-related impacts of climate change will arise from the on-farm consequences of a reduced level of service and disruptions to supplies. Upgrades of irrigation schemes are unlikely, given the expense and authorisation difficulties. Rural water supply schemes would be more easily upgraded and the costs for this critical service are more likely to be accepted.

There is a wide range of possible on-farm adaptation strategies to better utilise rainfall, local water supplies and scheme supplies. Improvements to soil health and structure, with the development of topsoil, would allow better soil moisture retention and soil moisture utilisation. To maintain farm productivity the emphasis should be on farm practices and better utilisation of local water and soil resources. Local adaptation could include on-farm or small-scale storage through land contouring and localised storage in depressions or side valleys, and by creating local wetlands for water retention and release storage. The costs and benefits of these adaptation measures would vary greatly, and be different from site to site, and region to region.

On-farm adaptation will depend on a wide spectrum of factors and influences, including production returns, relative costs of inputs and the costs and benefits of different farming practices. The impacts of climate change will be just one factor in the decision-making about future farming practices and adaptation strategies. Other changes in the physical environment, as well as in social values and priorities, economic conditions and price variability, and political decisions and policies, will all have an influence on future farming practices, land productivity and economic returns.

A number of documents used by designers and operators of rural water infrastructure schemes were reviewed. This included Irrigation New Zealand (INZ), The New Zealand Society of Large Dams (NZSOLD), and other pipe line and canal design related documents. These documents generally contained no specific comments or design recommendations related to climate change. To ensure that climatic effects are considered in the design and operation of rural water infrastructure, it is recommended that guidance notes are incorporated into these organisations' publications.

The effects on Maori related to climate change impacts of rural infrastructure were assessed. Little information exists about the effects of climate change on rural water infrastructure and Maori society. However, the effects of climate change are likely to have a significant impact on rural Maori communities, namely those communities which are currently under financial pressure to maintain existing rural water infrastructure. This situation is likely to have direct effects on community health, wellbeing and the ability for communities to generate income from the land. Maori society will need to have a voice in the local political discussions relating to this topic. The possible effects and implications on Maori culture, health, knowledge and economic enterprises will be of significance to whanau, hapu and iwi. There is scope for carrying out further research to gain a better understanding of the future challenges and the adaptation tools which will be needed to sustain traditional and contemporary Maori values.

A number of recommendations for future actions were identified. These focus on determining how climate change could be factored into water infrastructure management and potential solutions to minimise climate change impacts on rural water infrastructure. Actions are proposed at a national, scheme and on-farm level.

Actions at a National Level

1. Arrange awareness and education programmes with all rural water scheme owners and managers to inform them of likely changes to their respective scheme performance. This will enable them to plan for the future and take into account climate change effects. One method would be to promulgate the findings of this project through the farmer friendly fact sheet and the case study summaries;

2. Provide a forum through which climate change effects on rural water infrastructure can be incorporated into guidance documents, design guidelines, etc that can be used by rural water infrastructure designers and owners. This could be through Irrigation New Zealand and/or a practice note through IPENZ. This is necessary to provide for effective and consistent planning for climate change impacts on existing scheme performance and new scheme design;

3. Facilitate regional programmes in association with Irrigation New Zealand and the territorial authorities on remediation measures against climate change impacts;

4. Promote research on changes in irrigation water demand under different climate change scenarios. This could be undertaken by AgResearch, NIWA, Landcare or any other relevant research providers under FoRST funding programmes;

5. Promote research on increased stock water drinking demand under different climate change scenarios. This could be undertaken under the FoRST funding programmes. The focus needs to be on areas where there is a significant increase in hot days exceeding 25°C. This applies mainly to the Northland region;

6. Promote regional forums (workshops and seminars) to enable climate change effects and impacts to be discussed and alternative technologies and agricultural practices to be presented. This is to encourage farming systems and agricultural and horticultural practices to plan and adapt to climate change effects; and

7. Promote research to better understand the impacts on Maori society, and the adaptation tools that will be required to sustain traditional and contemporary Maori values. The research should focus on the impacts on rural Maori communities and issues with maintaining existing rural water infrastructure. This will have direct effects on community health, wellbeing and the ability for communities to generate income from the land.

Actions at a Scheme Level

1. Assess and review current scheme performance and integrity against future climate conditions, including codes of practice and operational documents;

2. Develop a “plan of action” to future proof the schemes against the potential physical changes likely to be caused by climate change impacts and effects. Build in resilience at scheme level by upgrading, if required as part of ongoing management;

3. Review condition of all off-farm assets to ensure fitness for purpose for future conditions;
4. Investigate potential economic and financial impact on scheme productivity; and
5. Provide for a contingency fund for climate change related impacts.

On – Farm Actions

1. Commence increased monitoring of stock drinking water use and stock drinking patterns;
2. Review irrigation water use efficiencies and application techniques as a climate change adaptation strategy;
3. As part of the on-farm asset renewal programme, review asset role and “climate proof “ the replacement asset according to climate change impact predictions;
4. Adapt farm management practices to take into account climate change related impacts; and
5. Adjust irrigation application rates to take into account climate change effects on rainfall and evapo-transpiration.

Potential Solutions for Adaptation Against Climate Change Impacts

1. Set up monitoring programmes to identify and project more closely climate change impacts to allow for proper planning of projected impacts;
2. Where appropriate replace or renew intake screen cleaning devices with automated devices;
3. For storages involving spillways, review spillway capacities and upgrade capacities to comply with the new national dam safety regulations;
4. Ensure budgets for scheme operations and maintenance are sufficient to cope with any increased costs associated with adapting to climate change;
5. Ensure replacement of all assets take into account likely climate change impacts over the life of the asset; and
6. Undertake a comprehensive review of future water demands coupled with a review of likely availability of water resource in the future and revise scheme level of service accordingly.

1 Introduction

The overall long term goals for climate change adaptation in New Zealand, as agreed by land based sectors, Māori, local and central government are to ensure:

- Reduced vulnerability to a changing climate.
- Resilient farms, forests and rural communities.
- Opportunities presented by a changing climate are captured.

MWH has been commissioned by the Ministry of Agriculture and Forestry (MAF) to assist in gaining a broad understanding of the physical impacts of climate change on rural infrastructure, including agricultural and horticultural production systems, and identify the key issues and potential solutions to these impacts.

MAF is interested in understanding the potential impacts of droughts, floods, more intense rainfall events, wind and increased temperatures on rural infrastructure, including smaller community irrigation schemes, stock water races and farm storage. In particular, this report has assessed the effects on:

- Structural integrity and/or operation of storage areas, dams, spillways, intakes, pipes, irrigation channels and on farm reticulated systems.
- Altered average temperature on water races and any impacts on weed growth or water quality.
- Sediment and/or erosion control issues.
- Changing management or maintenance requirements.

The relevant effects, issues and solutions are illustrated through a series of case studies.

From the results of the case study analyses a national 'roll up' of potential impacts of climate change impacts was undertaken. An attempt has been made to assess economic impacts on farming operations and likely increases in operation and maintenance costs.

A series of recommendations have been made on future actions for the management of rural water infrastructure along with potential solutions for remediation against climate change impacts.

More details on the scope of the work, as provided in the brief from MAF, are given in Appendix A.

2 Project Methodology

2.1 Case Study Selection

Five irrigation schemes were selected to develop case studies, as detailed in section 3.1.1. These schemes were selected on the basis of geographical spread from Northland to Southland, rainfall distribution, source river morphology, the nature of the infrastructure and the region's potential for climate change. Between them, these case studies incorporate the following key components, ensuring that the full range of infrastructure from fish screens to pipes is assessed:

- Schemes with storage;
- Canal schemes;
- Canal schemes transitioning to pipe conversion;
- Piped distribution schemes; and
- Different intake types.

A further case study on rural stock water supply (RWS) schemes has been developed. This case study comprises seven schemes that MWH has been involved with during investigation, design or construction. These schemes, which are listed in section 3.1.2, are considered representative of both the wide range of infrastructure involved in reticulated rural water and the climatic zones most influenced by climate change.

2.2 Hydrological and Meteorological Assessment

The Ministry for the Environment document *Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand – 2nd Edition* (2008), was used to identify the likely future changes to the climate in the regions for each case study. This MfE document has scaled down the findings from the IPCC Fourth Assessment Report to show the climate change effects for New Zealand.

The assessment for this report comprised sourcing details from the MfE Guidance Manual and other relevant literature on a number of climate change effects. The following effects were assessed for each case study region:

- Changes to rainfall distribution. This assessed changes to the rainfall at both the locations of the infrastructure and at the headwaters or catchment areas for the schemes. It also included assessment of changes to snowfall for the southern case studies.
- Increase in frequency of heavy rainfall events.
- Changes to air temperatures, including changes to the number of frost-free days.
- Potential for extended periods of drought.
- Sediment and/or erosion control issues.
- Groundwater levels and saltwater intrusion.
- Changes to wind speed and direction.

The hydrological analyses have included assessment of projected trends of seasonal rainfalls and river flows, and impacts on the potential evapo-transpiration deficits (PED) in the scheme areas.

2.3 Water Temperature Effects

The outputs of the hydrological and meteorological assessment, in particular the changes in air temperature and rainfall distribution, form the basis for the assessment of water temperature effects.

The potential effects that were investigated as part of the case studies were the impacts on water quality and aquatic ecology of water races, including effects on weed growth. This included an assessment of the impacts on water quality and aquatic ecology of the natural water bodies which feed water races, and on minimum flow requirements for those water bodies. Water temperature effects were assessed using a four phase methodology:

1. Literature search into the linkages between climate change and water quality/quantity, and on consequences for aquatic ecology.
2. An analysis of the various ways in which these factors could interact for each case study to highlight site specific versus broad scale effects. This analysis was used to assess likely impacts of increase in water temperature on weed growth and water quality for each case study.
3. Matrix type summary of potential effects.
4. Cost impact assessment of water temperature effects on the relevant infrastructure components.

2.4 Impact on Infrastructure

The infrastructure assessment was undertaken in a number of phases:

1. Asset inventory collection. Components of the rural water infrastructure were determined for each specific case study. This formed the basis for identification and discussion of the impacts on the infrastructure.
2. Existing operation and maintenance cost acquisition.
3. An assessment matrix was developed on impacts of climate change on infrastructure, based on assessment of hydrological, meteorological and water temperature effects. Traffic lights were used to identify the extent of the impact, with a red traffic light denoting a major impact, an orange light a moderate impact and a green light a minor or no impact.
4. Scheme managers were interviewed to attain their opinion on potential impacts, confirm MWH assumptions and supply additional information. This included details on infrastructure where the schemes have expanded or altered since construction.
5. Preparation of revised expenditure profile over the life of the scheme utilising assessed climate change impacts, as detailed in Appendix B.

2.5 Economic and Productivity Assessment

As part of the project investigations, an assessment of the potential effects on land productivity and economic returns has been undertaken. Two different methodologies were put forward. One involved a wide-ranging overview of the potential impacts on the case study schemes, with a general qualitative assessment. This provided a first-cut severity assessment, from marginal adjustments to significant modification costs, reduced levels of service with consequential declines in productivity, major land use or production adaptation, and at the extreme a system failure. The basis of the original economic evaluations of the schemes prior to construction were obtained, where available, and a general estimate was made of the impact of projected climate changes on scheme benefits.

The other approach involved a determination of additional capital and operational costs to maintain the existing or original (design) standard of the schemes. This is based on an assessment of the capital upgrades required to provide the present (design) supply of water (per area on a daily and seasonal basis), and/or additional operational requirements.

2.6 National "Roll-up"

A general overall assessment of what might be the national implications of these productivity and economic effects has been undertaken from the case study assessments. This involved a very broad determination of possible additional capital and operational costs, and how much this would impact on farm economics. The implications for farm management and potential impacts on land use and productivity were also considered.

A review of relevant industry publications identified how these documents could be revised to include assessment of climate change impacts in the design and upgrade of rural water infrastructure assets.

2.7 Effects and Implications on Maori

The impact of climate change on Maori society, with particular regards to rural water infrastructure, is an area where minimal research has currently been undertaken. For the purpose of this study, two key documents have formed the research basis in identifying the effects and likely implications of climate change on Maori. These documents include ‘The climate change matrix facing Maori society’ paper which can be found in the proceedings of the Climate Change Adaptation in New Zealand conference of 2010. Key information has also been identified in a submission made by Te Runanga o Ngai Tahu on the Central Plains Water Trust application to Selwyn District Council for land use consents and a requirement for designation. Both documents have been considered when identifying the effects and likely implications of climate change on Maori, relating to water infrastructure.

2.8 Future Actions and Recommendations

The results of the analyses were used to prepare a statement of future actions that focus on determining how climate change could or should be factored into water infrastructure management. Potential solutions or methods to minimise future costs were identified, and recommendations for future action were prepared.

3 Project Case Studies

3.1 Selection of Case Studies

3.1.1 Irrigation Scheme Case Studies

The five case studies that have been utilised for the irrigation scheme assessment are shown in Table 3-1. The schemes were selected to cover a range of geographic areas, climatic variations, catchment hydrology and scheme size, land use and infrastructure assets.

Table 3-1 : Case Study Schemes

Primary Case Studies	Region	Scheme Gross Area (ha)	Dairy	Sheep	Stock Water	Horticulture	Viticulture	Seed	Lifestyle
Kerikeri Irrigation Company	Northland	2,800	●	●		●			●
Tablelands Irrigation Scheme	Bay of Plenty	300	●			●			●
Southern Valleys Irrigation Scheme	Marlborough	4,500					●		●
Waimakariri Irrigation Scheme	Canterbury	18,000	●	●	●				●
Manuherikia Irrigation Scheme	Central Otago	2,245	●	●		●	●		●

A description of the schemes are presented below and further detailed in the case studies in Appendix C.

Kerikeri Irrigation Company Ltd

Kerikeri, Northland **2,800 hectares**

This scheme comprises two dams, 120 km of pipe and numerous smaller infrastructure to service approximately 350 shareholders, often horticulture and lifestyle farms. This case study allowed storage, spillways, pipes, valves, and on-farm systems to be assessed in a sub-tropical area where flood and intense rainfall events are common.

Tablelands Irrigation Scheme

Opotiki, Bay of Plenty **300 hectares**

This crop irrigation scheme includes approximately 40 properties over 300 hectares. The crops are mainly sub-tropical fruits and kiwifruit with some lifestyle block and stock water supply. The water source is the Otara River and the gravity reticulation system (dripper type on farm distribution) was constructed in 1981. The scheme has a design flow of 175 l/s and river gallery intake with a pumped storage of 500 cubic metres.

This scheme is a good case study from a climate change perspective as there are potential water temperature issues with respect to storage sizing in terms of demand, and intake performance problems with gallery intake blockages from increased weed and algae growth.

Southern Valleys Irrigation Scheme

Blenheim, Marlborough **4,500 hectares**

The new Southern Valleys Irrigation Scheme services approximately 4,500 hectares largely for viticulture and lifestyle purposes. The infrastructure is similar to the Kerikeri Irrigation Company scheme, but includes significant pumping. The water is sourced from the Wairau River, which is now subject to significant demand pressures. The Wairau River is also currently subject to the nearly completed resource consent process for the Wairau Hydro Scheme proposed by TrustPower that would abstract and return a significant proportion of the river flow. This scheme is likely to experience pressure on its infrastructure from many competing issues where climate change will play a significant role.

Waimakariri Irrigation Scheme

Mid Canterbury **18,000 hectares**

The Waimakariri Irrigation Scheme became operational in 1999, and was upgraded in 2002, so that it now services approximately 18,000 hectares. The scheme comprises a river intake from the Waimakariri River, a main race and distribution races supplying water to pastoral and mixed cropping land. It resembles an arterial system with race sizes reducing in size as side races are fed. There is potential competition and future constraints for the scheme, particularly with plans for other large irrigation schemes. The scheme does not include storage although the operators are currently considering this option.

Manuherika Irrigation Scheme

Clyde, Central Otago **2,245 hectares**

One of the first irrigation schemes in Central Otago, the Manuherikia Irrigation Scheme was opened in 1922. The scheme draws from the Manuherikia River and Chatto Stream, with some storage at Falls Dam, about 40 kilometres upstream of the main intake. The scheme is primarily a tunnel and open race network which supplies 2,245 hectares.

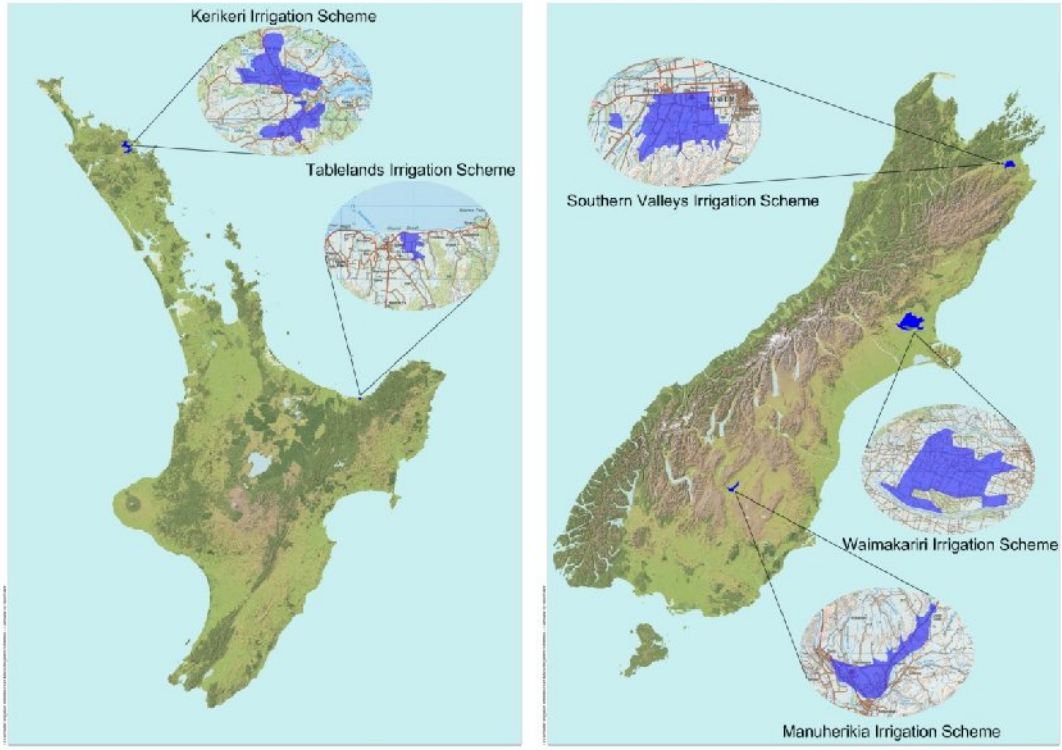

Figure 3-1: Location of Irrigation Case Study Schemes

3.1.2 Rural Stockwater Case Study

The rural water supply schemes for the rural water supply case study were selected to give a range of scheme types across a range of climatic regions. The seven schemes utilised for the case study assessment of rural stock water supply schemes are shown in Table 3-2 below. The full case study is in Appendix D.

Table 3-2 : Rural Stock Water Supply Case Study Schemes

Scheme	Area	Size (ha)	Farm Type	Water Supply
Cold Creek RWS	Taranaki	7,623 (107 farms)	Dairy	· On demand type scheme · Surface intake
Hunterville RWS	Rangitikei	10,000 (100 farms)	Pastoral	· Constant flow · Gallery intake
Wainuiouru RWS	Wairarapa	20,000	Pastoral	· Constant flow · Groundwater source
Redwoods Valley RWS	Tasman	2,500 (346 farms)	Pastoral/ Lifestyle	· Constant flow · Groundwater (Waimea Plains)
Malvern Plains RWS	Canterbury	200	Pastoral	· Constant flow · Gallery intake
Rocklands RWS	Otago	1,500	Pastoral	· Surface water intake
Homestead	Southland	2,200	Pastoral	· Constant flow · Shallow bores beside river

Figure 3-2: Location of Stock Water Supply Case Study Schemes

3.2 Approach Utilised with Case Studies

3.2.1 Irrigation Scheme Case Studies

Following scheme selection for inclusion in this study, the following approach was followed:

- MWH liaised with scheme managers to confirm inclusion of the scheme within this study, and identify their knowledge and opinions on likely impacts of climate change on their scheme.
- Where possible, scheme managers supplied MWH with a variety of documents including but not limited to:
  - *Investigation and Design Reports*
  - *Scheme Plans*
  - *Scheme Valuation Report*
  - *Annual Accounts*
  - *Photos.*
- All managers were interviewed by telephone and three of the scheme managers were interviewed face to face to discuss climate change impacts.
- Draft case study documents were prepared and forwarded to scheme managers for review and comment.
- Phone interviews were held with scheme managers to discuss the implications of the findings for their scheme.
- Final Draft case study documents were prepared and forwarded to scheme managers for a final comment and proof read.

Most of the irrigation scheme operators that were consulted during the course of this study indicated an awareness of climate change and generally believe they have been experiencing the effects of it. However, the scheme operators were generally unaware of the direct implications of these effects and how it would impact their business. The case studies provided them with their first formal overview on how they may be impacted by climate change and how they could respond to these impacts.

A general comment stated during interviews with operators was that the scheme users were aware of climate change and eager to know its impacts. However they can only manage what they know, not what they don't know. This study has informed the participants of areas that were previously partially unknown to them.

3.2.2 Rural Stock Water Supply Scheme Case Study

The focus of the rural water case study was to assess the potential impact on rural water supply infrastructure. The following approach was adopted:

- Scheme design and asset management details were sourced from MWH design files and/or scheme management asset management documents.
- Where the original scheme economic analyses were sourced from original scheme files, these were used as a basis for the economic assessment.
- Current operational and maintenance budgets were reviewed as part of the economic assessment.
- The different rural water supply schemes were analysed for their infrastructure componentry.
- Specific climatic and ecological analyses were undertaken for the different climatic regions for the scheme locations. The detailed climatic and ecological analyses were included as an appendix to the rural water supply case study, and are set out in Appendix E.
- This information was used to prepare case studies for each of the different scheme types.

3.3 Overview of Climate Change Effects

3.3.1 Hydrological and Meteorological Effects

The major climatic changes in each of the case study regions is summarised below. The full hydrological and meteorological assessment that was completed for each of the case study regions is detailed in Appendix E.

3.3.1.1 Changes to Air Temperatures

The hydrological and meteorological assessment found that the temperatures in New Zealand are projected to increase, with mid-range projections increasing by about 0.9°C by 2040 and about 2°C by 2090. The pattern of warming is fairly uniform across each of the case studies, although the northern schemes, both Kerikeri and Tablelands, will experience slightly higher increases.

Projected decreases to frost days is greatest in the south, where at Manuherikia there will be up to 10 additional frost-free days by 2050 and 20 days less by 2100. The change is the least in the far north, at Kerikeri Irrigation Scheme, where frost is a rare occurrence anyway.

3.3.1.2 Changes to Rainfall Distribution

The pattern of projected average rainfall changes (mid-range projections) in the five key irrigation scheme case study areas is summarised in Table 3-3 below by season. An upwards facing arrow indicates a projected increase in seasonal rainfall due to climate change, and downwards facing arrow indicates a projected decrease. Little, or no, change is represented by 'nc'. Rainfall changes for the Southern Valleys Irrigation Scheme and the Waimakariri Irrigation Scheme are considered in terms of both the upper catchment area (i.e. Wairau and Waimakariri river headwaters) and the area the scheme is located in. The left portion of the table for these schemes (HW) represents the headwaters of the catchment.

Table 3-3 : Project Seasonal Rainfall Changes for Irrigation Case Study Schemes

	Summer		Autumn	Winter		Spring	
Kerikeri (Northland)	No change		No change	↓		↓	
Tablelands (Opotiki)	↑		↑	↑		↓	
Southern Valleys (Blenheim)	*HW* ↓	↑	↑	*HW* ↑	nc	*HW* ↑	nc
Waimakariri (Canterbury)	*HW* ↓	↑	↑	*HW* ↑	↓	*HW* ↑	nc
Manuherikia (Central Otago)	↑		↑	↑		↑	

Summer rainfall across the scheme areas is projected to either remain similar to the current situation or increase. The exception being the upper catchment areas of the Southern Alps that feed into the Southern Valleys and Waimakariri schemes where summer rainfall will decrease. Autumn rainfall remains the same in Kerikeri while increasing at all other schemes. Winter rainfall is projected to increase apart from at Kerikeri and the Southern Valley and Waimakariri scheme areas.

Spring rainfall will decrease in the North Island schemes and increase or remain the same in the south.

At opposite ends of the country the Kerikeri scheme will receive less overall rainfall while the Manuherikia scheme will receive more.

Climate change impacts on snow will result in a decrease in snow lying at high altitudes. This could impact on lower river flows at the intakes to irrigation schemes fed by rivers draining high ranges such as the Southern Valleys and Waimakariri schemes. Reduced spring snowmelt would result in lower river flows.

3.3.1.3 Frequency of Heavy Rainfall Events

Extreme heavy rainfall events are projected to increase in magnitude and/or frequency across all of the case study areas. The frequency of extreme rainfall is projected to double at all scheme locations by 2090.

3.3.1.4 Potential for Extended Periods of Drought

The frequency of extreme drought events will increase, despite the expected increase in average rainfall in some locations. A current 20-year average recurrence interval (ARI) potential evapo-transpiration deficit (PED[1]) is projected to double in frequency and occur approximately every 10 years at all irrigation schemes.

The greatest increase in the occurrence of days with temperature in excess of 25°C is in the far north. The Kerikeri area can expect 10 to 20 additional days where the temperature exceeds 25°C by 2050. Projected increases in hot days are less moving southwards. The Manuherikia area can expect up to 5 extra hot days by 2050.

3.3.2 Water Temperature Effects

The major water temperature and water quality effects for each of the case study regions are summarised below. A full assessment on these changes and consequential impacts on the ecology of affected water ways is detailed in Appendix E.

[1] PED is a measure of drought or water deficit. It incorporates the climatic factors of rainfall, temperature and wind. PED is calculated for unirrigated land and is measured in millimetres. It can be thought of as the amount (depth) of water needed to supply a crop, in addition to actual rainfall. For example, a PED of 200mm over a growing season could be overcome by applying 200mm of irrigation water at appropriate times.

3.3.2.1 Water Temperatures

With the projected increases in average air temperature, of 0.9°C above current levels by 2040 and 2°C by 2090, an increase in average water temperature of streams and rivers is also projected across each of the case study regions. The magnitude of that change is subject to a number of factors including:

- Stream base flows and water depths: projected lower base stream flows and shallower water depths will contribute to increased water heating in summer.
- Intactness of riparian vegetation: streams from which riparian vegetation has been cleared and shading over waterways reduced are far more susceptible to summer heating than those which have retained a closed canopy. Restoration of riparian vegetation, already widely promoted by some Regional Councils, has the potential to offset temperature increases in small to medium sized waterways.

For schemes that are fed from wide or moderately wide rivers, the extent of shading that can be achieved from revegetation of riparian rivers is limited. This applies in particular to the Waimakariri Irrigation Scheme, the Tablelands Irrigation Scheme that is fed by the Otara River and the Southern Valleys Irrigation Scheme which is fed by the Wairau River. As a result of limited shading, these rivers are highly susceptible to warming in summer conditions.

In the case of the Kerikeri Irrigation scheme, average water temperatures in the two storage reservoirs are expected to increase approximately in line with average air temperatures. The Waimakariri Irrigation Scheme, where with 250km of irrigation races the water can take up to 48 hours to travel from the river to the end user, is particularly susceptible to summer warming.

3.3.2.2 Water Quality and Aquatic Ecology

Increased temperatures in the rivers and storage reservoirs that feed each of the schemes covered in the case studies, coupled with increased sediment and nutrient inputs and increased atmospheric carbon dioxide levels, may increase the likelihood of nuisance algae blooms, weeds, pest fish or other unwanted organisms in the future. This may lead to possible consequences for the quality of water distributed throughout each of the irrigation and stock water supply schemes. Serious weed infestations or algae blooms could lead to increasingly variable pH and dissolved oxygen regimes, with possible consequence for scheme infrastructure. This may include clogging of screens and the possibility of increased pipe corrosion. Increased sediment loads in the river resulting from more frequent heavy rainfall events will also have possible consequences for maintenance of scheme infrastructure.

Potential adverse effects associated with summer heating of rivers and catchments, together with reduced summer flows, may intensify the debate around a sustainable residual flow regime for rivers feeding some of the schemes, such as for the Southern Valleys Irrigation Scheme. This may potentially lead to a reduction in the quantity and quality of water available for irrigation and stock at critical times. Where appropriate, these issues may lead to a renewed focus on remediation measures such as riparian planting programmes and targeted afforestation in erosion prone scheme catchment areas.

Didymo has been confirmed in some of the rivers feeding the irrigation and stock water schemes, such as in the Wairau and Manuherikia rivers, however it has not yet been observed at nuisance levels for any of the case study assessments. There is some evidence of a survival limit for this species at a mean air temperature in the coolest month of ~5.5 ^{o}C, i.e., this species may not be able to maintain a presence if temperatures increase above this level (although this is yet to be proven).

3.3.3 Impacts on Infrastructure and Potential Response Options

3.3.3.1 Irrigation Schemes

A detailed inventory of the impacts of climate change on irrigation scheme infrastructure is presented in Appendix G. Table 3-4 is a summary of the infrastructure assets, the likely key impacts and various response options based on the findings of the case studies.

Table 3-4: Impact of Climate Change Effects and Potential Response Options for Irrigation Infrastructure

Scheme Component	Impact	Response Options	Extent of Impact
Dam Structures	Lower operating levels	Increase observation and maintenance	
	Lake weed growth	Likely increase in off take screen capacity and mechanical screen cleaners	
	Increased flooding means storage reservoirs may fill easier	Nil	
	Increased droughts	Lead to less dam spills	
	Temperature increase	Land use change and possible capacity increases in reservoir needed	
Dam Spillway	Increased flood flows Increased focus on dam failure Increased emergency planning	Increase in spillway capacity required Increase in compliance costs	
Canal maintenance	Flood damage	Increase in repairs	
Intake Screens	Weed clogging Sediment erosion	Increase screen capacity of intake Install mechanical screen cleaner	
Sediment cleaning	Increased head pond and pipe sediment cleaning Increased canal sediment cleaning	Increase removal of sediment	
Weed cleaning	Increased weed growth and cleaning, intakes, canals, pipes	Increase removal of weed	
Pumps	Weed and sediment induced wear and tear of hydro mechanical equipment. Reduced pump life through increased pump use due to increased demand use patterns.	Increase servicing of equipment and reduce equipment life span	
Pipe Network	Reduced pipe life span due to cracking of pipes due to drought shrink and wet ground expansion.	Increase in pipe repairs	
	Reduced pipe life span due to sediment erosion or water quality.	Intake sediment removal Maintenance and observation	
	Increased operating and maintenance due to drought.	Increase labour	
On farm irrigation	Canal cleaning Damage and clogging to service lines and spray heads	Increase operating and maintenance costs on farm	

Table 3-5 details the operating and maintenance costs that are possible as a result of climate change, based on the impact assessment. In addition to operating and maintenance cost impacts are capital costs, or one-off upgrades to the schemes possible as a result of climate change. These are detailed in the case study summaries presented in Appendix C. The case studies also document response options and effort has been made to differentiate required responses from ageing assets, or required by consent changes from impacts attributable to climate change.

Table 3-5: Changes to Operation and Maintenance Costs for the Irrigation Case Studies

Case Study	Current O&M Costs ($/ha/year)	Future O&M Costs, including impact of climate change ($/ha/year)	Percentage increase in O&M costs due to climate change
Kerikeri Irrigation Company	60	69	15%
Tablelands Irrigation Scheme	197	382	94%
Southern Valleys Irrigation Scheme	62	87	40%
Waimakariri Irrigation Scheme	12	24	98%
Manuherikia Irrigation Scheme	117	166	42%

3.3.3.2 Rural Stock Water Supply Schemes

Table 3-6 provides a summary of the infrastructure assets for rural stock water schemes, the likely resulting impacts and various response options based on the findings from the case study. The types of rural water supply schemes were differentiated in the case study, according to whether they were on-demand or constant flow, and pumped or gravity fed. The detailed case study in Appendix D presents detail on the impact as a result of climate change and potential response options for each type of scheme.

Table 3-6: Impact of Climate Change Effects and Potential Response Options for Stock Water Supply Infrastructure

Scheme Component	Impact	Response Options	
Bores close to the coast	Potential saltwater intrusion	May require additional bore source due to decline in yield or require shifting bores due to saltwater intrusion.	
Bores	Lower groundwater levels and reduced yields	May require additional bore sources due to decline in yield from reduced recharge.	
Intakes	Weed clogging and sedimentation	Increase in screen cleaning and intake maintenance. May require increase in intake capacity due to increased demand.	
Pumps	Change in duty due to increased flows and increase in heads	Increase in demand will require upgrade of pumps with additional flow capacity.	
Treatment processes	Increased usage with more wear and tear	Will most likely need to be upgraded in line with additional flow requirements.	
Rising main	Additional sedimentation and reduced level of service	Possible hillside stability issues requiring more maintenance, particularly in Nelson area.	
Main reservoir size	Stability issues with sub surface conditions. Overall water usage increased impacting level of service of main reservoir.	Increase storage capacity to maintain level of service.	

Scheme Component	Impact	Response Options	
Gravity reticulation	Gravity reticulation – reduced level of service	Network capacities and pipeline sizing will need to be reviewed against increased demands.	
On farm storage	Reduced level of service	Increase storage capacity.	
On farm reticulation	Reduced level of service	Improve on farm reticulation to accommodate increase in peak demands.	

3.3.4 Economic and Productivity Assessment

3.3.4.1 Irrigation Schemes

The economic impacts of projected climate changes on irrigation schemes will vary, depending on their regional location, the type of infrastructure and existing and potential land uses. The case studies demonstrate a range of impacts and varying vulnerabilities.

An overall assessment of economic and productivity impacts on the five irrigation schemes was undertaken generally in accord with the first methodology. This assessment is based on the hydrological and meteorological analyses that has been undertaken for the scheme areas. These analyses have covered the catchment of the water supplies and the irrigation scheme area itself.

Table 3.7 summarises relevant information on the nature of the schemes, the projected increases in PED, the constraints on per hectare supply from the scheme infrastructure and from abstraction or allocation restrictions. This data has been rounded off and generalised from that obtained from the project investigations. It shows that there are significant differences in scheme infrastructure that limit flexibility and increasing the supply of water to the scheme area, and in the impacts of projected climate changes.

The projected increases in PED over the season are relatively similar around the country, at approximately 100 mm. However, the effect of this increase on the irrigation scheme varies greatly, depending on the present seasonal deficits. The very high deficits that already occur in Marlborough mean that the increase is a small proportion of the scheme design. By comparison, the present deficits at the Tablelands scheme are relatively small, and thus the increase is a large proportion of the deficit on which the scheme was designed. In summary, where daily and seasonal water deficit is large, then the proportional impact of the projected changes in PED is relatively small. The security of supply depends on whether the source is a river or storage reservoir, likely changes in river flows or storage inflows, and other competing uses of the water resource, including in-stream or environmental flows.

The schemes all have complex infrastructure, with distribution networks designed for specific water deficit conditions and hence fixed supply rates. The high costs of irrigation (compared to farm returns) means efficient and effective design is important, and schemes are constructed to relatively strict design standards and specified supply rates. There is little flexibility to accommodate increased supplies. The various components (pumps, filters, flow controls, etc) have been sized for specified flows, and the pipe or race network engineered to a given standard and flow distribution to the land of the scheme. All available water is made use of, and while more effective use could be made of the water that is supplied by schemes, this is an on-farm matter for individual property owners or shareholders.

Providing a larger daily watering rate has implications through the whole of the irrigation scheme, from the intake to the on-farm irrigation system. The schemes with horticultural land use supply design flows to on-farm systems that are piped to drippers or micro-sprinklers, and have control systems for rotational watering. The turnouts can also have flow restrictors, pressure reducers and filters.

The restrictions on increasing seasonal supplies of water also depend on the type of scheme, with storage schemes being limited by the reservoir capacity. The operational use of the storage affects this limitation, depending on the usefulness of summer inflows or dependence on over-season storage. For run of the river supplies the main restrictions will come from variations to allocations under consents. This will depend on the competition for the water from other irrigation schemes, other river uses (such as hydro-power) and environmental flow requirements. The importance given to the river environment and the natural character of rivers and lakes will affect allocations, in addition to changes in flows from climate change.

Potential impacts on the operation and maintenance of the case study irrigation schemes have been assessed as part of the study, and increases in operational costs estimated. These costs depend on the type of scheme and its location, but generally arise from the effects of additional weed growth and sediment supply on intakes, along scheme reticulation networks and within on-farm distribution systems.

This assessment generally follows the second methodology, with the additional costs being compared to on-farm costs, and the total cost of production for the relevant farm enterprises.

Some marginal increases in supply rates may be economic in pump and pipe schemes, by increasing pump flow rates, or adding in-line booster pumps within the reticulation network. However, this would increase energy costs. The operation and maintenance costs may increase due to a range of factors from a changing climate, as indicated by this project. These additional costs will also be variable and site specific, although there are some costs that may be generally applicable, such as from increased weed growth affecting intake and distribution facilities.

The additional annual costs from minor scheme modifications and extra power, maintenance and cleaning requirements are likely to be relatively small in comparison to on-farm servicing and production costs.

The complexity of the schemes and the constraints on upgrades (or their high cost) mean that the most likely adaptation will be on-farm. The irrigation schemes will continue to give significant advantages to the landowners within the scheme areas, in terms of both yields and land use flexibility. This should cushion the more adverse impacts of climate change, most especially prolonged droughts, but there would still be comparative declines in productivity compared to present conditions. That is, the average productivity or yield would decline (over years) due to lower soil moisture levels and more prolonged periods of plant stress.

Table 3-7: Summary of Irrigation Schemes used for Economic and Productivity Assessment

FACTORS\SCHEME	KERIKERI	TABLELANDS	SOUTHERN VALLEYS	WAIMAKARIRI	MANUHERIKIA
Potential Evapo-transpiration Deficits					
Average increase	90 – 120 mm	30 – 80 mm	120 – 150 mm	90 – 180 mm	~ 100 mm
1:20 year deficit	350 → 425/500 mm	200 → 350/400 mm	895 → 950/1000 mm	465 → 525/600 mm	645 → 700/715 mm
% increase	20 – 40 %	75 – 100 %	5 – 10 %	12 – 30 %	~ 10 %
TYPE	Lake Storage	Run of River	Run of River	Run of River	River Storage
Facilities	Boost pumps Piped	High lift Pumps Piped	Pumped Piped	Gravity feed Races	Gravity feed Races
RESTRICTIONS					
Daily supply	Pipe network Turnout limitations	Pump capacity Pipe network Turnout limitations	Pump capacity Pipe network Contracted volumes	Race network	Race network
Seasonal supply	Storage capacity				Storage capacity
ALLOCATION	Upper catchment streams – reduced winter inflow.	From lower reaches of river – increased summer flow.	From lower reaches of large river – decreased summer flow.	From lower reaches of major river – decreased summer flow.	Upper catchment streams to dam plus local stream – increased inflow.
Competition	Minimum low flows – similar summer rainfall. Existing scheme covers much of lower catchment area.	Relatively small coastal plains, and demands low compared to river flows (Waioeka & Otara rivers).	Supplementing groundwater. Competition from other land, with area of scheme reduced.	Competition from other large schemes, and pressures on minimum flows.	Shared storage, and other potential irrigation land.

3.3.4.2 Rural Water Supply Schemes

The impacts on the water supply schemes of the projected effects of climate changes were similar for all regions, with some exceptions. For an assessment of the economic and productivity impacts, these general impacts on the schemes were considered.

The rural water supply schemes provide stock water to large areas of farm land. The water demand for these schemes is much smaller than for irrigation schemes, and very much smaller on a per hectare basis. Given the priority accorded domestic and stock water, future restrictions on supply are unlikely for the projected climate changes of the study. The impacts will be on scheme operations and the service level given increased stock water requirements with increasing temperatures, the effect on peak demand of higher maximum temperatures and the number of very hot days during summer months.

Schemes with direct river intakes and screens would be affected in the same way as irrigation schemes with direct intakes. Given the low water takes of rural water supply schemes many intakes are indirect, through infiltration galleries or bores beside the river channel. These intakes and groundwater supplies will be little affected, if at all, by changes in river water flows or quality.

The schemes are generally flow restricted, with a continuous and constant flow to each property. The peak demand on farm is managed through on-farm storage reservoirs. If peak stock water demand increases, both on-farm and off-farm infrastructure would have to be upgraded. Most of the schemes have a pumped supply to storage reservoirs, and the distribution network is fully piped. Thus additional flow could be delivered by adding extra pump and reservoir storage capacity. This additional capacity could be installed as add-ons, and would have a small area footprint within the rural landscape.

The importance of stock water for animal health and productivity makes scheme upgrades a likely response following episodes of high stock stress because of prolonged droughts or a period of very hot days beyond that of past experience. The schemes would face the same organizational issues as irrigation schemes with respect to landowner agreement about upgrade options and financing. Consent variations may also be required, depending on the type of upgrade.

Economic evaluations carried out at the time of scheme approval have been obtained for three of the case study schemes (Cold Creek, Hunterville and Wainuioru). These evaluations were based on benefits from increases in stock carrying capacity, improved stock performance and hence productivity, and saved costs of pre-existing supplies, mostly on-farm dams or springs and creeks. The estimated increases in stock numbers were around 10 to 15% of farm carrying capacity, while improved stock performance (over all farm stock) could be 50 to 100% of the benefits from greater stock numbers.

The increase in stock numbers was because of better grazing management from more watering points and subdivision fencing, while the more accessible and better quality water of the scheme supply improved stock health and performance. For the projected climate changes, the grazing management benefits of the schemes, which included on-farm reticulation and subdivision fencing, would probably not be much affected. The installed infrastructure remains in place and continues to provide this benefit, albeit with higher stock watering demands.

Climate changes may affect stock carrying capacity for reasons other than water supply, in terms of the amount of water available to stock and the number or proximity of watering places. The more severe the extremes of temperature and dryness, the greater the pressure on stock in terms of both feed and water. A sufficient supply of water is critical to stock health and the maintenance of sufficient stock condition to minimise longer term effects.

The additional stock performance and stock numbers resulting from the schemes could be affected by the impacts of the projected climate changes of the study. This would reduce farm production and hence economic returns. However, the overall impacts on farm economics is likely to be relatively marginal, with other impacts and market changes in produce price and farm costs being more significant.

The likely responses would be a combination of scheme upgrades and reduced stock numbers, where the supply constraints of the existing schemes were having significant impacts.

The scheme infrastructure, both off and on-farm, could be significantly impacted by an increase in the intensity of storm events, or the frequency of high rainfall events. The infrastructure of these rural water supply schemes is vulnerable to erosion and landslide damage. Many of the piped distribution networks pass through steep and erosion prone land, while storage reservoirs and pump stations may also be at relatively high risk from these hazards. Operation and maintenance costs could then be affected by these hazards. However, these additional costs are not predictable.

The rural water supply schemes would be less affected by impacts on river flows and quality than irrigation schemes, given their low per hectare demands for water and generally less exposed and at risk intake systems. The water demand of stock is related to plant watering requirements (of dryness and water deficits), but is not the same, and the effects on stock of water restrictions have not been well researched.

Having sufficient water for stock through dry periods is critical for stock health and condition, while the relatively low flow rates and piped reticulation of the schemes makes add-on upgrading more practical for these schemes. These upgrades would increase operational costs, such as power charges, as well as the capital investment required. At the same time, there could be some increase in operational costs at intakes, although probably relatively small. Costs could increase for other reasons as well, for instance from more erosion and slip damage.

The rural water supply schemes provide a critical service to farms, and like irrigation schemes, they will provide significant advantages to the landowners within the scheme areas, in terms of water security and management flexibility.

Figure 3-3: Rocklands Rural Water Supply Water Treatment Plant

4 Climate Change Impact on National Rural Water Infrastructure

4.1 Rural Water Infrastructure National Component Summary

The case studies enabled a master list of the scheme infrastructure to be compiled. Much of the basic components are common to both irrigation and rural water supplies. The main difference being the relative magnitude of the infrastructure due to the vastly different design flow rates between irrigation and rural water supplies. The scheme component summary is set out below:

- Intakes
- Screens
- Bores
- Rising mains
- Storages pumps
- Mechanical items
- Reticulation pipe networks
- Canals
- Treatment systems
- Pumps
- Farm turn out systems
- On-farm storages
- On-farm reticulation.

Each of the potential climate change impacts were then assessed against possible impacts on the various rural water scheme infrastructure components.

Figure 4-1: Main Race at Manuherikia Irrigation Scheme

4.2 Climate Change Impacts

4.2.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) has produced a full assessment of the current state of scientific knowledge on human induced global warming and what it means for the world. Global climate change projections have been derived from General Circulation Models (GCM) of a number of scenarios of future greenhouse gas emissions.

To identify likely future climate changes across New Zealand, projected changes from 12 GCM's have been statistically downscaled by NIWA and published in the Ministry for the Environment document *Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand – 2nd Edition* (2008).

4.2.2 Hydrological and Meteorological Impacts

New Zealand is expected to warm throughout the 21st century, but less than the global average. Most models also project a general increase in westerly winds, which would lead to a shift in average rainfall patterns with generally more rain expected in western parts of the country and less in the east.

Mid-range projections are that New Zealand's annual average temperature will increase by about 0.9°C by 2040 and about 2°C by 2090. Uncertainty around the downscaled model results means there is a wide range around this of 0.1°C to 2.6°C and 0.6°C to 5.9°C by 2040 and 2090 respectively.

Across New Zealand the pattern of warming is fairly uniform, although northern regions will experience slightly higher increases. Mid range projections show that on a seasonal basis the North Island has greater warming in spring, summer and autumn. During winter the South Island has the greatest projected warming.

With the exception of the east coast and far north of the North Island, average annual rainfalls are expected to increase. However, there will be seasonal changes particularly in Canterbury, Marlborough and in the far north. Summer rainfall across most of New Zealand is projected to either remain similar to the current situation or increase. The exceptions being in the upper catchment areas of the Southern Alps where summer rainfall will decrease. Spring rainfall will decrease in the North Island and increase or remain the same in the south.

Extreme heavy rainfall events are projected to increase in magnitude and/or frequency across the entire country. Every projected 1°C increase in mean temperature means the atmosphere can hold 8% more moisture. The frequency of extreme rainfall is projected to double at all scheme locations by 2090. That means that a current heavy rainfall event with a 1 in 20-year chance of occurring could have a 1 in 10-year chance of occurring by 2090.

Similar to the expected increase in the frequency of extreme rainfall events, the frequency of extreme drought events will increase. This is despite the expected increase in average rainfall in some locations. A current 20-year ARI potential evaporation deficit (a measure of drought or water deficit) is projected to double in frequency and occur approximately every 10 years at all irrigation schemes

Climate change impacts on snow will result in a decrease in snow lying at high altitudes. This could impact on lower river flows at the intakes to irrigation schemes fed by rivers draining from high ranges. Reduced spring snowmelt would result in lower river flows.

Projections of changes to extreme temperature are provided over a range of emissions and model scenarios. The greatest increase in the occurrence of days with temperature in excess of 25°C is in the far north, with up to 20 additional days. Projected increases in hot days are less moving southwards.

Conversely, projected decreases to frost days is greatest in the south (up to 10 days less by 2050 and 20 days less by 2100) and the least in the far north where frost is a rare occurrence anyway.

4.2.3 Effects on Water Quality

The New Zealand natural environment has undergone great changes in the past, with constant fluctuations at all spatial and temporal scales. The conservation ideal is a self-sustaining ecosystem capable of responding to natural change (McGlone 2001). It is therefore not change itself that is the issue. However, anthropogenically driven climate change poses new challenges, particularly in terms of the magnitude and speed of change.

McGlone (2001) identified four main classes of change likely to impact on New Zealand's indigenous biota and their ecosystems over the next 100 years:

1. Alteration of latitudinal and altitudinal ranges with movement of species and communities southwards and upwards, accompanied by disruptive transitions;
2. Strong impacts on biota and ecosystems already under stress if extreme weather events become more frequent and severe;
3. Changes to productivity and nutrient cycling within ecosystems due to a combination of climate change and carbon dioxide increases;
4. Disruption of freshwater ecosystems through low flows or drying of streams and rivers and warming of water.

The most serious and pressing problems may arise through the interaction of climate change with pre-existing threats to the biota. In freshwater streams it is likely that climate change will have its greatest impact in modified landscapes with low resilience, through increasing exotic weed and pest pressure and disrupting ecosystem processes. For instance modified rural or urban streams with deforested catchments and reduced riparian vegetation will be more susceptible to increased primary production and warming effects, including increasingly variable pH and dissolved oxygen regimes (Wilcock et al 2008).

Temperature is a fundamental variable in aquatic ecosystems and in the case of invertebrates virtually all facets of life history and distribution of aquatic insects are influenced by it. Quinn and Hickey (1990) suggest that high water temperature could explain the absence or low abundance of temperature sensitive mayflies and stoneflies from New Zealand rivers where summer temperatures exceed around 20°C. While most native fish in New Zealand are able to thrive within a wide range of water temperatures, some native species and the exotic brown trout prefer cooler temperatures and may be adversely affected by increases (Jowett 1990; Richardson et al 1994).

Warmer temperatures may also increase the risk of invasion by warm temperate exotic species. McGlone (2001) identifies a strong gradient of increasing species richness towards the equator and that each degree of temperature increase in New Zealand widens the zone from which invasive species can be selected. One example, *Gambusia* (mosquitofish) was introduced at Auckland in 1930 and has since spread through much of the North Island, with recent introductions to the South Island. *Gambusia* has been implicated in the displacement of native fish.

Scheme operators generally expressed significant concern about possible outbreaks of didymo, an invasive species that was first detected in New Zealand in the lower Waiau and Makarora Rivers in Southland in 2004. Didymo has now spread to at least 26 rivers in the South Island. It is almost invariably found in cooler, mountainous regions, but whether temperature is a limiting factor in its distribution remains to be proven (Kilroy et al 2007). If that were found to be the case, climate warming might be expected to reduce its range in New Zealand, and might reduce the risk of it spreading through the North Island. There is evidence that many Hawke's Bay rivers, which regularly reach 28°C or higher in summer, may be too warm for this species. Nevertheless, Didymo is a recent example of an invasive non-indigenous species capable of causing widespread disturbance in some New Zealand waterways. An economic impact assessment undertaken by the New Zealand Institute of Economic Research in 2006 found that the impacts are dominated by reduced recreation values, loss of existence values associated with extinction of native species and reduced tourism expenditure, followed by increased costs for maintenance of municipal, industrial and agricultural water intakes (which could become clogged).

The risks for irrigation and rural water supply schemes will vary depending on location and infrastructure in place but in general terms include the following:

- Warmer water temperatures leading to increased risk of new invasive organisms in source streams, reservoirs or water distribution races, with possible implications for scheme management and infrastructure.
- Warmer water temperatures and lower flows in source streams placing native aquatic biota under increasing stress, potentially leading to more rigorous residual flow requirements and reduced allocable water.
- Warmer water temperatures and increased carbon dioxide levels leading to increased aquatic plant productivity in source streams, reservoirs or water distribution races, with increasingly variable pH and dissolved oxygen regimes and increased algae biomass. These effects have possible implications for scheme management and infrastructure associated with clogging of screens, pipe corrosion and oxygen depletion, etc.
- Higher frequency of droughts which would increase water demand and exacerbate the above effects.
- Higher frequency of heavy rainfall events which may offset some of the effects listed above, for instance by scouring macrophyte and periphyton growth from the beds of rivers and streams. More frequent heavy rainfall may also increase sediment yields and erosion within stream catchments, with potentially adverse effects on irrigation scheme infrastructure.

4.3 Impacts on Water Infrastructure

4.3.1 Irrigation Schemes

The following section describes the findings of the case studies with respect to the potential impacts of climate change on the physical infrastructure. The assessment has been determined by the opinions of MWH and based on interviews with scheme operators.

A general observation was that the newer the scheme was, the more likely it is to be less susceptible to the identified climate change impacts. Many of the scheme boards were acutely aware of the potential impacts of climate change and were exceedingly grateful to be participants of the study. Many schemes however appeared to be grappling with more issues surrounding water efficiency, which entails infrastructure changes such as supply system conversion to pipe or creation of storages.

4.3.1.1 Intakes

For all case studies there was considered to be a number of potential impacts on water intakes. For many schemes the change in hydrology indicated increased magnitude of floods, and change in durations of these events. This has benefits of cleaning the river beds of debris and reducing river maintenance, but conversely potentially more sediment and changes in river morphology could require more effort to divert water to intake structures.

Temperature effects are likely to produce more debris and weed which was identified as a significant impact on intake screens if they existed, or the need for new screens if they didn't. Operation and maintenance costs associated with new screens, and screen cleaning were identified as significant by operators.

Figure 4-2: Otara River and Intake Structure for Tablelands Irrigation Scheme

4.3.1.2 Storages

Only one case study (Kerikeri) owns its own sizeable storage. The Manuherikia scheme has part share of the Falls Dam storage, which was not included in the case study assessment. Several other case study schemes are considering on-farm or scheme storage as part of their assets.

Sedimentation of reservoirs and weed growth is likely to increase. The general impression is that these impacts will not be significant on storages, however as detailed above the weed issue is expected to impact on the screens and intakes.

The most notable storage issue is the change in rainfall pattern, particularly heavy rain intensity and duration. The effect of this change is likely to result in storage spillways being undersized for higher flows.

Dam regulations have recently been changed under the Building Act 2004, and new Dam Safety Regulations are to be in force on 31 July 2010. The authority for resource consents and building consents now lies with Regional Authorities. The emphasis of the Building Act 2004 is dam safety.

Dams are required to have spillways and their capacities must meet the New Zealand Society of Large Dams (NZSOLD) 2000 guidelines. It is likely with changed hydrology that spillways will be ‘under designed’ and upgrades of these will be required to ensure a dam is ‘safe’. The capital cost of spillway upgrades is significant and likely to pose significant costs on scheme shareholders.

An under-capacity spillway can also potentially lead to the classification of a dam as a ‘Dangerous Dam’ under clause 157 of the Building Act 2004. Under this categorisation, Regulatory Authorities have significant powers to undertake works to remedy any faults. The choice of whether or not to upgrade spillways is therefore not necessarily at the discretion of scheme owners.

4.3.1.3 Screens

All case studies highlighted the importance of screens as part of the infrastructure and the impacts climate change may have on them. For those schemes that had no screens, scheme operators identified that screens would be required, either to exclude fish or to manage increases in weed and debris resulting from increased flooding and warmer water temperatures.

For irrigation schemes, issues surrounding screens typically involved enlargement, through increase in screen size, mesh and adding more screens, to ensure blockage increases would not reduce potential take allowances. Additional costs will be incurred due to operation and maintenance flow-on requirements.

4.3.1.4 Pumps and Mechanical Items

Pumps, valves, offtakes and other associated mechanical equipment could be affected with the likely increase in use and subsequent reduction in useful service life. Additional pump and mechanical maintenance and/or replacement is anticipated through increased wear and tear on equipment, exacerbated by sediment load changes and water quality.

4.3.1.5 Pipes

Three case studies are largely pipe distribution. For these schemes, the operators expressed minimal concern that the identified climate change impacts would impact severely on the integrity of the pipe systems. The potential for extended drought patterns was a concern in more northern schemes with clay based soils, where ground shrinkage and subsequent swelling when ground moisture levels increase will cause excess pipe cracking. This concern was itemised as an operation and maintenance cost. The anticipated water pH level changes due to water quality are not considered significantly detrimental to pipe life spans.

Figure 4-3: Laying Pipes for Southern Valleys Irrigation Scheme

4.3.1.6 Earth Lined Canals

The climate change impacts on canals are likely to be linked to increased weed growth and sediment accumulation due to water quality changes and increased heavy rainfall induced sediment mobilisation respectively. Canal sediment and weed growth for schemes is generally addressed as a single operation and finance item, as cleaning generally removes both at the same time. As the sediment and weed growth impacts in canals are difficult to predict, the assessment of potential change was made on the basis of the increased likely frequency, and by scaling of operational costs accordingly.

Minor effects were identified as increased slips, seepage as a result of canal liner cracking, and subsequent canal over-flows in the event of excess capacity inflows from rainfall events and the damage this induces.

4.3.2 Rural Stock Water Schemes

The following section summarises the findings of the potential impacts on rural water supply scheme infrastructure. The rural water supply case study covered several different types of rural water supplies in different climatic regions. An interesting finding was that the different components of a rural water supply scheme were all affected to a greater or lesser extent by climate change. Two exceptions for general conclusions to be drawn were:

1. In the case of ground water takes only bores near the coast are likely to be affected by saltwater intrusion.
2. The issue of increased problems with didymo due to climate change was most likely to be more prevalent in the south of the South Island.

4.3.2.1 Surface Water Intakes

There are a number of potential impacts on water intakes for the rural water supply schemes with surface water intakes. These impacts were similar to those identified in the irrigation case studies. For each of the schemes the change in hydrology indicates increased floods, and change in durations of these events. This has benefits of cleaning the river beds of debris and reducing river maintenance, but conversely potentially more sediment and changes in river morphology with potentially more effort required to divert rivers for extraction and to maintain existing intakes.

Temperature effects are likely to produce more debris and weed which was identified as a significant impact on intake screens where they existed, or the need for new screens if they didn't. Operation and maintenance costs associated with new screens, and screen cleaning were identified as potentially significant. Many rural water supply schemes have gallery type intake structures. The stream flow characteristics are likely to change as a result of climate change which will potentially impact on high flow water quality and sealing off of infiltration beds due to weed and increased macrophyte growth during low flow. In the first instance some increase in turbidity is expected at high flows and increased maintenance of the infiltration bed zones at low flows is to be expected.

4.3.2.2 Bores

Bores are considered to be a reliable source of water for rural water supplies. Under climate change scenarios, inland bores and bores close to the coast will potentially be affected by less recharge and therefore potentially lowering of water levels. There will need to be on-going monitoring of water levels to identify any accelerating trends in water level changes and any potential changes in bore yields.

The case study analysis for the Redwoods Rural Water supply scheme which has bore sources near the coast identified potential issues with saltwater intrusion due to sea level rise and reduced recharge. The saltwater intrusion issue is likely to be common for many groundwater areas near the coast. The interim measure to assess potential effects will be to increase monitoring for salinity at the source bore and adjacent observation bores near the coast. The ultimate adaptation measures will be to either relocate the bores further inland or potentially reduce yields from affected bores and construct additional bores.

There is expected to be an impact on gallery performance from climate change effects. This is due to both more frequent flood flows resulting in effects from additional sedimentation, and in low flows due to additional weed and macrophyte growth causing a blinding off of the infiltration zones. Both effects will result in additional maintenance and the need to monitor gallery performance more regularly. More regular scarification of the bed will be required. Consent conditions may need to be varied to allow for these additional operational maintenance activities.

4.3.2.3 Pumps

Most rural water supplies are reliant on pumps in some part of their network or system. Pump systems have defined duty points (i.e. they operate at a specific pressure and flow) and as such provide a fixed delivery of water. Climate change impacts that affect either pumping heads (in the case of lowering of water levels in bore systems) or increase in flows (in the case of increase in peak water intake from stock due to an increase in frequency of hot days greater than 25 degrees) will have direct effects on scheme performance or level of service. Pump performance will need to be monitored and pump duty reassessed in light of climate change impacts. When pumps are due for replacement at the end of their asset life, the pump duty will need to be checked. A pump with a different duty may be required due to changed conditions as a result of climate change impacts affecting both flows and pumping heads. Pump system performance will need to be monitored more regularly in all cases.

The other aspect of pump performance likely to be affected is a result of an overall increase in demand for stock water due to higher temperatures. Such an increase will involve longer pump running hours with an associated increased frequency of pump replacement and/or additional pump and mechanical maintenance.

Figure 4-4: Manuwai Pump Station at Kerikeri

4.3.2.4 Treatment Processes

It is anticipated treatment processes will be largely unaffected apart from potentially needing to increase treatment plant capacities due to increased demand. The increase in overall demand will increase chemical usage where applicable with associated increase in production and running costs. Depending on the treatment process design in some instances, additional front end treatment may be required to treat increases in sedimentation and turbidity. Any treatment process improvements need to be assessed on a case by case basis.

4.3.2.5 Rising Mains

Rural water supply schemes typically have significant rising mains from river surface sources. The climate change analyses have identified that with frequency of storm events, there will be increased vulnerability to the stability of the rising mains. The security of these mains will need to be checked. An adaptation measure could be to provide for additional emergency piping and joints/couplings for temporary repairs in the event of failure.

4.3.2.6 Off Farm Storages

Rural water supply storages are unlikely to be affected by climate change impacts. Structural design tolerances under projected climate change effects are within the range of projected changes.
Long term projections on demand need to be checked in terms of storage capacity under climate change. It is likely that in several regions storage capacity will need to be increased to maintain existing levels of service.

4.3.3 Common Items to Irrigation and Stock Water Supply Schemes

4.3.3.1 Off Farm and On-farm Reticulation

The analyses of climate change impacts on rural water supply reticulation networks have indicated that the material and installation techniques are likely to be able to stand up to the projected changes. As with the rising mains, stability of pipeline routes need to checked and if necessary contingency plans put in place and/or rerouting of reticulation in the long term to more stable areas.

The water demand issue needs to be reassessed in light of increased peak demands. Pipeline sizing can then be reviewed to check whether the level of service can be maintained under increased demand scenarios. Providing the pipe class is satisfactory, installation of pumps at the farm turnout may provide a solution for the on-farm network capacity.

4.3.3.2 Farm Turnouts

The farm turn out arrangements need to be reviewed in light of potential increased demand. Where pressure reducing valves (PRVs) are involved, adjustment will be required to maintain the level of service.

4.4 Potential National Economic and Productivity Effects

4.4.1 Irrigation Schemes

Irrigation schemes involve the transport of relatively large volumes of water over extensive areas. Scheme infrastructure is generally complex with long distribution networks; and careful engineering design and construction to specific design (water deficit) standards is undertaken to keep costs down. This also minimises water demand.

While projected climate changes give rise to similar temperature and average rainfall increases throughout New Zealand, there are significant differences in the impacts on potential evapotranspiration deficits (PED). Seasonal changes in rainfall do vary around the country, and the effects on source river flows may be different to the effects at the irrigation area. The projected increases in PED are relatively similar throughout NZ, but vary from a small proportion of existing seasonal PEDs to a large proportion. The marginal effects are then quite different in different regions.

The capital costs of constructing irrigation schemes are high (compared to farm returns). However, operating costs are generally low compared to other farm expenses, especially with horticultural land uses. Upgrading schemes to provide higher rates of water supply would be expensive, and would need to be well managed to obtain the necessary agreement and consents with a minimum of difficulty and time.

Landowners within irrigation schemes have significant advantages in terms of land use flexibility and productivity, and this is likely to become more significant with the projected climate changes. The likely responses to changing climatic conditions are then to maintain schemes as much as practical at their existing design standard or supply rate, while adapting on-farm to accommodate the effects on farming practices, management and production.

Reduced waterway low flows over longer and hotter dry periods are likely to increase the competition for water resources and the in-stream requirements of environmental flows. This could give rise to reduced supply rates, increasing the need for on-farm adaptations and improvements in soil moisture management.

The main impacts on scheme operations arise from increased clearing of intakes and distribution races, additional repairs due to flood and storm damage, and upgrades from safety considerations, such as enlarged spillways at dams to pass higher flood flows. Schemes will be affected differently, depending on whether they have storage reservoirs, main river intakes, pump and pipe networks or open race distribution.

The larger capital costs would be upgrades of dams to meet safety requirements, while the larger increases in operational costs would be from greater intake and screen debris cleaning, and canal and race cleaning requirements. The estimated costs for the works required because of the impacts of the projected climate changes are generally not large in comparison to on-farm expenses.

The estimated increase in annual operation and maintenance costs for the five case study schemes is about $500,000. That gives an average annual increase of around $20/ha. The latest national statistics (of 2002) give a total area under irrigation systems in NZ of 467,700 ha. Taking 500,000 ha of irrigation and presuming that the overall average of the representative schemes approximately applies to all irrigation, whether by a community scheme or from on-farm systems, a national estimate of additional cost would be about $10 million per year. Capital upgrade costs would be in addition to these operational costs.

These costs are very approximate, but would be a small proportion of farm gross revenues and costs.

4.4.2 Rural Water Supply Schemes

Stock water supply is a critical infrastructure for pastoral farming in New Zealand. While there is generally a range of water supplies on farms, water quality can be very variable. Over large areas of New Zealand farm land there are extensive piped water supply schemes, which normally involve pumping and reservoir storage. These schemes have allowed better stock management, through a greater number of watering points and further sub-divisional fencing, and have given rise to improved animal health and productivity. Stock health and farm production now depends on these reticulated supplies, and many previous supplies, in particular farm dams, would probably no longer be functional today with such supplies.

The most serious increased risk to rural water supply schemes from projected climate changes may be that from erosion and landslide damage. An increase in the frequency/intensity of storms would have a direct impact on the amount of damage to scheme structures and especially the reticulation network. The likelihood of a loss of supply and the downtime until supplies were restored after storm events would increase. A lack of resilience in the scheme infrastructure, and of back-up supplies on farm, could result in serious detrimental impacts on stock health and farm production when scheme supplies are cut by storm damage.

The water demands of rural water supply schemes are relatively small compared to other demands, and the abstractions are generally only a small proportion of the source stream or river low flows. One of the benefits of extensive community schemes was that reliable water resources could be used. Domestic and stock water is also a priority demand on water resources. Thus supplies are not likely to be affected by the projected changes in temperature and rainfall, in terms of water availability at source.

In contrast, on farm supplies from dams, springs and creeks could likely be affected, with reduced flows and greater evaporation losses, especially during hot dry periods and prolonged droughts. The east coast areas would be the most likely to be affected.

The capacity of water supply schemes is restricted. If maximum stock water demands increase with more hot days at higher temperatures, then scheme upgrades would be necessary to maintain stock health and productivity. There does not seem to be any useful information on what these increases in stockwater demands may be. The upgrades would involve greater pump and reservoir capacity, and potentially re-laying of larger sized pipes, but no practical estimate can be made of these potential costs.

National herd figures can be used to give an overall picture of stock water demand and some idea of the potential order of cost increases from climate change impacts on existing scheme infrastructure. These costs can then be related to other farm costs or working expenses.

Combining the peak daily water consumption values used in the design of stock water schemes and total stock numbers, maximum national stock water demand is around 700 million litres a day. This is based on 5.9 million dairy cattle, 4.5 million beef cattle and 32.5 million sheep, and does not include other stock, such as deer and pigs.

The area in grassland farming in NZ from the latest (2002) national statistics is around 8 million hectares (excluding tussock land grazing – of about 3.25 million hectares). The operational costs of the case study rural water supply schemes can be taken as a guide to rural water supply costs, whether on-farm or through community schemes. This would suggest an average per hectare cost of around $20. Then assuming additional costs from climate change impacts are in the order of 20-30%, the increase in costs to pastoral farming nation-wide may be around $50 million.

The per hectare cost increases of about $5 can be compared to total farm working expenses for the MAF national sheep and beef model budget (at 6-7½ stock units per hectare) of $250-275/ha, or for more intensive sheep and beef farming of around $500/ha.

Thus while stock water supplies are critical, the cost of the rural water infrastructure to supply farms is relatively small, compared to other farm costs. The more important issues are likely to be continuity of supply and water quality for prime stock health.

4.5 Publication Review

The publications reviewed as part of this study did not typically address the potential impacts of climate change directly. Inclusion of content in these publications that directly identifies the potential impacts from climate change and provides some guidance or design advice to protect against the variability would be of significant use for scheme owners and planners. This section identifies how these publications could be improved to integrate climate change response to their use.

4.5.1 Irrigation New Zealand Publications Assessment

Irrigation New Zealand (INZ) is an industry body formed to promote irrigation development and efficient water management, see Appendix F for more details. This project has incorporated a review of various INZ documents to determine if and how they can incorporate climate change aspects with respect to irrigation infrastructure. Failure to incorporate climate change effects will lead to sub optimal scheme design and financial impacts to shareholders. As such, inclusion of the effects of climate change as a note to designers, contractors, scheme owners and managers is recommended.

The published documents reviewed were:

- The New Zealand Irrigation Manual, (INZ), 2001
- Code of Practice Irrigation Evaluation, (INZ), February 2006
- Code of Practice Irrigation Design and Installation (INZ), March 2007
- (DRAFT) Farmers Guide to Design Code of Practice.

General review of all INZ documents indicates no significant allowance for the impacts of climate change as part of codes of practice or guidance.

With new and existing schemes there is intense pressure to minimise water loss and realise the value of water conveyed. As such many traditional canal based schemes are considering, or being forced through water efficiency measures to consider, pipe conversion which will significantly alter infrastructure requirements. Coupled with climate change, there is uncertainty on the impacts and its effects on infrastructure. As an example, at the Kakahu Irrigation Scheme in South Canterbury the existing intake system and fish exclusion system was recently replaced with a significantly more expensive capital cost system, due to water temperature changes and the proliferation of *Didymo.*

The interrelated issue of infrastructure and climate change is a growing concern to irrigation scheme shareholders. This was highlighted recently in the presentation to Waimakariri Irrigation Ltd shareholders by Craig Scott (MWH), Maurice Duncan (NIWA) and Dr Terry Heiler (Heiler Associates Ltd). At this meeting NIWA presented on climate change impacts on irrigation based on the MfE report *Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government New Zealand,* and the discussion of the impacts of climate change in infrastructure assets was hotly debated. Climate change was a central theme to the 2010 Irrigation New Zealand Conference.

Climate change effects on infrastructure are principally focused on the intakes (sedimentation and screens), pipe distribution and storage dam spillway impacts. INZ are planning guidance on many of these topics in upcoming studies.

4.5.2 New Zealand Society of Large Dams (NZSOLD) Publications Assessment

The *New Zealand Society of Large Dams* (NZSOLD) is the industry body formed to advance the technology of dam engineering, see Appendix F for more details. This project has incorporated a review of NZSOLD published documents to determine if and how they can incorporate climate change aspects with respect to irrigation infrastructure. The brief for this study did not include review of NZSOLD documents, however during the study the climate change impacts on dam infrastructure were noticeable in terms of the financial impacts, and extension of the document review to NZSOLD publications was included.

The documents reviewed were:

- New Zealand Dam Safety Guidelines, (NZSOLD), November 2000
- Guidelines on Inspecting Small Dams, (NZSOLD), 1997.

This study has identified that the impacts on storages due to climate change could be significant. This applies to irrigation schemes that have storages or reservoirs, and to those that are proposing some form of on-farm storage.

The principal effect of climate change is projected high risk intensity rainfall, leading to increased flood flows. As a result, the current spillway capacity and ability to withstand a design return period flood event will be reduced. Conversely for a given return period flood such as 1:100 year spill capacity, the spillway may in the future be insufficient in terms of bypass capacity and capacity upgrades required. This issue is highlighted as dams have a significant public image with respect to safety and the impacts of the risk of failure.

With respect to the two NZSOLD guidelines, neither directly addresses the impacts of climate change. Hydrological variability is at the discretion of the dam designer in NZSOLD documents, and ranges of acceptable design criteria for spillways and other aspects are given which do allow flexibility for change to be accommodated.

NZSOLD are planning a revision to the publication, *New Zealand Dam Safety Guidelines.* It would be beneficial to incorporate an advisory note in the guidelines highlighting the potential impacts of hydrological climate change based on the NIWA work.

4.5.3 Various Publications Review

4.5.3.1 Pipelines

The other key irrigation infrastructure potentially affected by climate change is pipes. This project has highlighted the potential air temperature increases, and likely water temperature increases potentially leading to reduced pH and low oxygen content of water. This condition potentially affects the life span of pipes.

It should be noted that rural water supply infrastructure pipelines utilise many material types which react differently to changes in water quality. Typical pipe types are:

- Glass or fibre reinforced pipe (GRP or FRP)
- Steel
- Concrete and asbestos lined steel
- Ductile Iron
- PVC
- Polyethelene (PE).

Existing pipe standards are detailed in many publications such as:

- Product supplier pipe guidelines
- New Zealand design codes for all pipe types
- Local authority design guidelines.

A review indicates that these documents do not directly include an allowance for climate change in the design of pipelines. Pipe design does include factors of safety and other allowance buffers, however change of water quality factors such as acidity are often not a focus of design.

The MAF funded report *Comparison of Piped and Open Channel Distribution of Irrigation Water Supplies* is a foundation report for irrigation with respect to pipes. This report includes no reference to climate change or its potential impacts.

4.5.3.2 NZ Infrastructure Asset Valuation and Depreciation Guidelines

No formal methods for determining the impacts of climate change on existing infrastructure or new infrastructure have been sourced. Section 4.6 of the *NZ Infrastructure Asset Valuation and Depreciation Guidelines 2006* provides a very useful tool that could be adopted and modified to assess the impacts of climate change on a scheme infrastructure's asset life span, and predicting the financial impacts of change. The guideline does not specifically account for climate change, however by design these factors can be accounted for.

Figure 4-5: Storage Pond at Waimakariri Irrigation Scheme

5 Effects and Implications on Maori

Te Reo Maori and Maori culture as a whole has evolved in the unique New Zealand landscape. Traditions surrounding harvesting methods and art forms vary for individual regions and are often driven by the natural character of the surrounding landscape. Flora and fauna locality, which is determined by climatic conditions, has defined important taonga species which may either be prevalent or nonexistent in any given region.

Carvings made from local indigenous timber tell stories of the manu which flew in the surrounding forest. Kete were woven from the raupo at nearby wetlands and korowai were knitted together with the muka of the abundantly growing harakeke. Local weather patterns determined crop success, harvesting times and the best locations for food gathering. As a result of their early struggles for survival, Maori gained extensive knowledge of New Zealand's often harsh climate.

It is these functional aspects of the New Zealand landscape which have determined where iwi and hapu traditionally settled and built pa. These landscapes were commonly close to the natural resources which ensured their survival and these places are where iwi and hapu continue these traditions today, often in a more contemporary sense.

Today Maori settlements are often still located in the rural landscape close to natural resources, including rivers, streams, lakes, and wetlands. These settlements are often in the same or similar locations to the original sites. Resources in these landscapes have gradually degraded and are already stretched in some regions. Climate changes are likely to affect Maori society at multiple levels.

Individual whanau, communities, hapu and iwi will all be affected in different ways and varying scales. Water quality is fundamental to the health of rural Maori communities. A reliable rural water supply is vital to maintain and support the wellbeing of whanau, kura kaupapa and marae. Climate change will also affect commercial Maori enterprises and economic developments. The price of maintaining rural water infrastructure has serious financial implications for communities which are already under stress from existing infrastructure that is in a poor condition. One of the greatest concerns for Maori society in this rapidly changing climate is the potential adverse effect on rural water resources and infrastructure.

The relationship Maori have with water is complex and multifaceted. Water plays a significant role for Maori in the process of breaking tapu or sacredness and creating noa, the profane. The relationship between water quality and water flow are essential in retaining cultural values of importance to Maori.

Water continues to play a key role in everyday Maori lifestyle, where Maori continue to swim in the streams which their ancestors once bathed in centuries ago and where food is gathered using traditional methods which were developed over generations.

The flow of a river or stream not only supports terrestrial and aquatic life, it also holds mauri and wairua values, a spiritual essence and life-force, for Maori. The natural flow of a water course also contributes to its mauri and sacredness. Climatic changes are likely to result in increased rainfall in some areas of the country which may result in increased water levels along a given watercourse. It is also likely that national temperatures will increase in some areas of New Zealand, causing drought and reduced water levels.

Increased water flows may cause flooding of riparian margins which provide habitat for indigenous species. Flooding of riparian margins will not only result in loss of habitat for indigenous fauna, it is also likely that indigenous plants which flourish in these ecological buffers may be lost. Increased rainfall and greater upstream flow may also have implications for the dilution of brackish estuarine water, altering salinity levels and therefore impacting on both flora and fauna.

With the likelihood of flood risks increasing, historic trails and archaeological sites are also placed under threat. The flow of a river, for example, may have determined safe crossing locations or food gathering spots which were revisited over generations. The way in which a river flows and behaves is part of the experience which travellers would have become familiar with and used to determine temporary settlement sites. Maori place names often relate to surrounding landscape features, and can reflect the natural flow and character of water courses. Archaeological sites and wahi tapu are also at risk of being flooded as a result of increased water flow.

Decreased water flow will inevitably effect water quality and increase water temperatures, which is likely to have greater impacts on Maori than increased water flow. High water quality and adequate water flow is required to sufficiently clear out pollutants and debris which may compromise habitat health. A decrease in water flow will create opportunities for exotic and invasive plant species to encroach into the exposed riverbed and will also reduce the inhabitable area for aquatic life. Decreases in water volumes may also result in the exposure of wahi tapu, middens and burial sites.

Water abstraction and increased irrigation demand commonly increases in the warmer months of the year. This is also when water temperature is naturally rising and aquatic ecosystems are already facing climate related stress. Increasing air and water temperatures resulting from climate change are likely to further reduce water quantities and have serious flow on effects on aquatic ecosystems. Terrestrial ecosystems in riparian margins also likely to be significantly impacted by reduced water quantities.

The broad implications for Maori as a result of decreased water flow include potential loss of taonga species due to habitat degradation, and the potential loss of ephemeral streams, springs and wetlands which hold strong historical and cultural values for individual hapu and iwi.

The economic implications of climatic changes to rural water infrastructure are also significant. With further pressure on rural water infrastructure the cost of abstraction and irrigation is likely to increase. Rural Maori communities who are already struggling to sustain horticultural and agricultural businesses may see greater costs which make these practices economically unviable. Rural water storage, which is also likely to increase in cost, may further decrease water flow levels and impact habitat health.

Land productivity, which is vital for the supply of food to rural whanau, marae and also for commercial purposes, is also likely to be effected by the impacts of climate change on rural water infrastructure. Reduced irrigation capacity will ultimately result in reduced yield from crops and a decrease in crop quality. The implications of this will affect rural Maori communities at multiple levels including the support of important cultural practices and hui undertaken at rural marae.

The intergenerational implications of climate change are also likely to be significant. As ecosystem health degrades, so too will the life supporting services which ensure species survival. Taonga species, which are often localised and of great importance to particular hapu, may be confronted with population loss and extinctions. Knowledge which is passed on through traditional art forms and practices, generation to generation, are also at risk of being lost.

Despite extensive local knowledge, which has been developed over generations, Maori are becoming increasingly vulnerable to the impacts of climate change on the cultural, social and economic aspects of Maori society. Unfortunately few papers have been written about the effects of climate change on rural water infrastructure and Maori society. Further research into this subject is required to gain a better understanding of the future challenges and the adaptation tools which will be needed to sustain traditional and contemporary Maori values.

An opportunity exists for further protection of important cultural landscapes which are likely to be affected by climate changes to rural water infrastructure. The inclusion of landscape aspects in infrastructure maintenance and upgrades will further protect this important cultural resource. Indigenous riparian margins, fencing which excludes stock from entering water bodies, and further planting of indigenous vegetation surrounding watercourses, are aspects which should be included in all water infrastructure maintenance and upgrades.

Maori society will need to have a voice in the local political discussions relating to this topic. The possible effects and implications on Maori culture, health, knowledge and economic enterprises will be of significance to whanau, hapu and iwi.

A definition of the Maori terms used in this section is shown in the glossary below.

Glossary

Hapu	Sub-tribe
Harakeke	*Phormium tenax,* NZ flax
Hui	Meeting
Iwi	Tribe
Kete	Woven basket
Korowai	Cloak (chiefly)
Kura Kaupapa	Maori School
Manu	Birds
Marae	Meeting area
Mauri	Life force
Muka	Flax fibre

Noa	Profane
Pa	Traditional stockaded village
Raupo	*Typha orientalis,* bulrush
Taonga	Treasure
Taonga Species	Culturally important species
Tapu	Sacred
Te Reo Maori	Maori language
Wahi Tapu	Sacred sites
Wairua	Spiritual essence
Whanau	Family

6 Options for Future Water Management

6.1 Introduction

This section details how climate change could or should be factored into water infrastructure management, and identifies potential solutions and methods to minimise future costs to managing water infrastructure.

6.2 Summary of Climate Change Effects

The effects of a changing climate on rural water infrastructure is summarised in Table 6-1. By understanding the effects on an irrigation or stock water supply scheme, appropriate adaptation and water management measures can be carried out by farmers and the industry.

Table 6-1 : Effects of Climate Change

Climate Change	Effect
Increase in rainfall	Higher rainfall and average river and stream flows will provide benefits for instream ecology and at times reduce pressure on the water resource.
Decrease in rainfall	Lower stream flows and potentially more rigorous residual flow requirements for source streams. Increased pressure on water resources.
Changing rainfall patterns	Seasonal variations may lead to increased pressure on water resources at times. Less water (or more water) available for storage at different times of the year.
Less snow fall and shorter snow melt season	Lower flows in spring and summer may lead to increased pressure on water resources at times.
Increased risk of drought	Increased frequency and durations of very low river and stream flows may at times increase pressure on water resources and stream ecology. Minimum/environmental flow could be reached more often and abstraction for schemes reduced or halted for periods of time.
Increase in average temperature; Increase in very hot days	Increased temperatures in source rivers and streams with potentially adverse effects on stream ecology. Increased temperatures in storages contributing to higher risk of nuisance algae blooms. Increased risk of weeds, pest fish or other unwanted organisms. May contribute to increased variability on DO and pH regimes. Potentially higher maintenance costs for scheme infrastructure due to clogging of screens and increased corrosion. May also increase the risk of invasion by other unwanted organisms (but possibly reduced risk associated with didymo). Increase in peak demand for stock watering.
Increased frequency of heavy rain events	Increased sediment and nutrient inputs to storages contributing to higher risk of nuisance algae blooms or weeds. Increased sediment yields and erosion in scheme catchments. Potentially increased maintenance costs for scheme infrastructure. An increase in the frequency of large floods may lead to re-evaluation of design parameters for storage lakes. Potential effects on pipeline stability.
Increased summer water deficit for un-irrigated land	Increased water demand for land currently in schemes.
Increased windiness	Coupled with an increase in temperature this could lead to an increase in erosion of topsoil.
Sea level rise	Bores near the coast will have an increased risk of saltwater intrusion.
Decrease in groundwater levels	Increase in pumping head.

Impacts on rural water infrastructure have been identified, and the additional costs to manage or remedy these effects have been estimated. These costs are small compared to farm enterprise costs and would not have serious impacts on farm economics.

There is other rural infrastructure that can be adversely affected, which would have higher cost implications, for example the district roading network and farm access ways. Power supplies and fencing are other extensive and exposed assets that are at risk from changing climatic conditions.

The most significant water-related impacts of climate change will arise from the on-farm consequences of a reduced level of service and disruptions to supplies. Upgrades of irrigation schemes are unlikely, given the expense and authorisation difficulties. Rural water supply schemes would be more easily upgraded and the costs for this critical service are more likely to be accepted.

There is a wide range of possible on-farm adaptation strategies to better utilise rainfall, local water supplies and scheme supplies. Improvements to soil health and structure, with the development of topsoil, would allow better soil moisture retention and soil moisture utilisation. To maintain farm productivity the emphasis should be on farm practices and better utilisation of local water and soil resources.

Existing irrigation and rural water supply schemes provide landowners with significant benefits, and the relative advantages of these schemes will increase with the projected climate changes.

6.3 Response Options

There are a number of remediation and adaptation measures that the industry and farmers could adopt to minimise the financial costs associated with a changing climate. This includes adoption of alternative infrastructure technology as outlined below. Possible response options are summarised in Table 6-2.

6.3.1 Intakes and Screen

There are many technologies for intakes and screens from filtration galleries buried in the river bed to pond screens with mechanical screens as cleaners. Each has advantages and disadvantages.

The case studies determined that the principal need will be for increased screen areas, or numbers, to ensure allocated takes could readily be met, with the addition of screen cleaning devices required by the increased screen areas.

Figure 6-1 below shows the new screen and cleaner required for the Kakahu Irrigation Scheme in South Canterbury, where a buried filtration gallery had to be replaced due to increased weed and Didymo clogging.

Figure 6-1: Intake of Kakahu Irrigation Scheme in South Canterbury

6.3.2 Pipes and Appurtenant Structures

Many canal schemes in NZ are considering conversion to pipe schemes. Accordingly pipes are considered the alternative delivery method for water. Conversion from pipe to canals is considered unlikely.

The RITSO and MAF funded study *Comparisons of Piped and Open Channel Distribution of Irrigation Water* details many issues associated with pipes and canals. A key consideration is the material selection of pipes. This is an issue for new schemes, and maintenance or conversion of existing schemes. Pipe selection will need to ensure that the pipe type selected does not degrade earlier than its design life with potential water quality changes resulting from climate change. Material types such as glass reinforced pipe (GRP), PVC and polyethelene (PE), may be favoured over coated steel and ductile iron, which may be susceptible to water quality changes.

6.3.3 Pumps and Moving Components

Various moving components, especially pumps are subject to wear and tear more readily than static components of infrastructure. There are no technological alternatives to these. However equipment prevention against wear and tear is continually improving, and correct equipment selection is essential to minimise advanced degradation of equipment.

Table 6-2 : Possible Response to the Impact of Climate Change

Climate Change	Impact	Response
Increase in droughts	· Reduced yields from existing storages · Increased peak water demand · Reduced pipe lifespan due to cracking of pipes from drought shrink	· Reduced production or requirement for increased storage · Increase in pipe repairs
Increase in flood risk	· Increased flood damages to key infrastructure intakes, pipeline crossings, etc	· Remediation measures to reduce flood damages · Increase in repairs · Increase in dam spillway capacities · Increased emergency planning and compliance costs
Increase in rainfall	· Increased peak runoff	· Increased culvert sizes · Identification of secondary flow paths
Changes in wind speed and direction	· Less stability in natural vegetation, more wind throw (already observed in the Horowhenua region)	· Contingency planning and changes to emergency management procedures
Increase in air temperatures	· Changes in air temperature · Changes in frost patterns	· Possible change in land use · Increase or decrease in frost protection mechanisms
Increase in stream temperatures	· Increase in weed growth · Increased clogging of rural water infrastructure screen intakes · Increased corrosion · Smothering of river beds reducing infiltration gallery intake performance	· Redesign intakes · Increased maintenance
Changing rainfall patterns	· Increased river flows · Decreased river flows · Aggradation of stream beds · Degradation of stream beds · Demand pattern changes · Seasonal variations may lead to increased pressure on water resources	· Additional water take maintenance · Additional river training · Additional dredging · River works to maintain intakes · Altered take regime
Sea level rise	· Impacts on hydraulic performance of drainage systems and drainage pumps	· More pumps · More maintenance · Less production · Remediation measures
Groundwater yields	· Lowering or raising of groundwater levels · Potential salt water intrusion	· Change or adaptation of pumping systems · Need for alternative sources of water or shift of bore location
Weed and algae growth	· Fish screen blockage · Canal cleaning · Irrigator blockage · Damage and clogging of service lines and spray heads	· New technology for alternative screening · Additional screen cleaning and intake maintenance · Operation and maintenance
Consent limit	· Increased flow · Decreased flow	· Additional take

Climate Change	Impact	Response
abstraction reliability	· Altered sedimentation patterns	· Decreased take · Maintenance changes
Intake ability to abstract water	· Intake blockage · Intake damage · Altered river morphology · Fish screen utilisation	· Increase in maintenance or automation of screen cleaning · Increase in repairs or alternative intake technologies · Additional river training · Additional maintenance

6.4 Climate Change and Water Infrastructure Management

6.4.1 On-Farm Adaptation

There is a wide range of on-farm activities that could be undertaken to adapt to a changing climate, for instance improving water efficiency. There are additional benefits in enhancing soil moisture retention and moisture availability, including increasing productivity under prevailing and future climatic conditions. Improvements in soil structure and health through changes in farming practices and land uses would increase the infiltration of the available rainfall and its retention and utilisation within the topsoil layer. Local adaptation could include on-farm or small-scale storage through land contouring and localised storage in depressions or side valleys, and by creating local wetlands for water retention and release storage.

The costs and benefits of these adaptation measures would vary greatly, and be different from site to site, and region to region. There appears to have been few investigations of the economics of these on-farm and local measures, in particular from a public interest or national productivity point of view.

There is unlikely to be any scheme failures due to the projected impacts on scheme operational costs or because of a totally inadequate supply, arising from the projected climate changes that are the basis of this study. There may be some scheme modifications to increase the rate of supply or seasonal allocations, but in general the level of service would decline, with consequential decreases in scheme benefits, of yields and land use flexibility.

On-farm adaptation will depend on a wide spectrum of factors and influences, including production returns, relative costs of inputs and the costs and benefits of different farming practices. The impacts of climate change will be just one factor in the decision-making about future farming practices and adaptation strategies. Other changes in the physical environment, as well as in social values and priorities, economic conditions and price variability, and political decisions and policies, will all have an influence on future farming practices, land productivity and economic returns.

6.4.2 Scheme Ownership

In all case studies there was a positive response to the project and great interest expressed in the project findings. Although outside the scope, it is considered that scheme ownership, scheme administration and scheme management will influence initiatives and responses to climate change impacts on rural water infrastructure. The different ownership structures, ranging from formal company structures to scheme committees managing scheme operations through the local authority structures, combined with their perception of risk and how to mitigate it, will affect the way the scheme can and will respond to the climate change impacts. Scheme participants will need to be briefed on potential climate change impacts and a response plan developed by the schemes' administrating body. Dissemination of the findings of the project to scheme participants will be important in terms of generating a response to the findings.

6.4.3 Co-benefits

The project scope was limited to assessing climate change impact on rural water infrastructure. The findings are clear in relation to physical impacts. Recommendations for future action are set out in section 7. The project team found early on in the project that the physical impacts of climate change on rural water infrastructure were only one relatively small part of the wider picture of impacts of climate change impacts on agricultural and horticultural practices.

Other aspects of climate change impacts affecting agricultural and horticultural production such as water availability, water use efficiencies, weed infestations, changing land use and land use practices were not addressed in this project. However, it became clear that response to these other issues needed to be considered when responding to the impacts on infrastructure. Conversely, by responding to the issues identified around the infrastructure impacts would give the opportunity to consider co-benefits that could be derived for the wider changes in agricultural and horticultural practices likely to be required under climate change.

6.4.4 Consideration of the Effects on Maori

Despite extensive local knowledge, which has been developed over generations, few papers have been written about the effects of climate change on rural water infrastructure and Maori society. It is essential that further research into this subject is carried out to gain a better understanding of the future challenges and the adaptation tools which will be needed to sustain traditional and contemporary Maori values.

The effects of climate change are likely to have a significant impact on rural Maori communities, especially those communities which are currently under financial pressure to maintain existing rural water infrastructure. This situation is likely to have direct effects on community health, wellbeing and the ability for communities to generate income from the land.

An opportunity exists for further protection of important cultural landscapes and indigenous flora and fauna in rural landscapes as part of the identification of effects of climate change on rural water infrastructure and Maori communities.

Maori society will need to have a voice in the local political discussions relating to this topic. The possible effects and implications on Maori culture, health, knowledge and economic enterprises will be of significance to whanau, hapu and iwi.

Figure 6-2: Waingaro Dam at Kerikeri Irrigation Scheme

7 Recommendations for Future Action

7.1 Introduction

The project has highlighted a range of impacts that arise from a changing climate that affect rural water infrastructure along with the potential impacts on productivity and economic costs. Climate change will impact on both the performance and long term operations of both irrigation schemes and rural water supply schemes.

The project has shown that climate change will impact on all rural water infrastructure schemes to a greater or lesser extent across all the NZ climatic regions. The project has also shown that climate change will impact on all the infrastructure components of rural water schemes.

Set out below are recommendations for future actions that focus on determining how climate change could be factored into water infrastructure management along with potential solutions to minimise climate change impacts on rural water infrastructure.

The project brief related to specific impacts of climate change on existing rural water infrastructure. The studies and analyses have shown that aspects of water demand are likely to have greater impacts on rural water scheme performances than actual climate change impacts on existing infrastructure. The water demand impacts need to be integrated with the potential physical impacts on rural water infrastructure identified in this project to give a complete picture of climate change impacts on rural water infrastructure.

7.2 Rural Water Infrastructure Management – Future Actions

7.2.1 National

1. Arrange awareness and education programmes with all rural water scheme owners and managers to inform them of likely changes to their respective scheme performance. This will enable them to plan for the future and take into account climate change effects. One method would be to promulgate the findings of this project through the farmer friendly fact sheet and the case study summaries;

2. Provide a forum through which climate change effects on rural water infrastructure can be incorporated into guidance documents, design guidelines, etc that can be used by rural water infrastructure designers and owners. This could be through Irrigation New Zealand and/or a practice note through IPENZ. This is necessary to provide for effective and consistent planning for climate change impacts on existing scheme performance and new scheme design;

3. Facilitate regional programmes in association with Irrigation New Zealand and the territorial authorities on remediation measures against climate change impacts;

4. Promote research on changes in irrigation water demand under different climate change scenarios. This could be undertaken by AgResearch, NIWA, Landcare or any other relevant research providers under FoRST funding programmes;

5. Promote research on increased stock water drinking demand under different climate change scenarios. This could be undertaken under the FoRST funding programmes. The focus needs to be on areas where there is a significant increase in hot days exceeding 25°C. This applies mainly to the Northland region;

6. Promote regional forums (workshops and seminars) to enable climate change effects and impacts to be discussed and alternative technologies and agricultural practices to be presented. This is to

encourage farming systems and agricultural and horticultural practices to plan and adapt to climate change effects; and

7. Promote research to better understand the impacts on Maori society, and the adaptation tools that will be required to sustain traditional and contemporary Maori values. The research should focus on the impacts on rural Maori communities and issues with maintaining existing rural water infrastructure. This will have direct effects on community health, wellbeing and the ability for communities to generate income from the land.

7.2.2 Scheme

1. Assess and review current scheme performance and integrity against future climate conditions, including codes of practice and operational documents;

2. Develop a “plan of action” to future proof the schemes against the potential physical changes likely to be caused by climate change impacts and effects. Build in resilience at scheme level by upgrading, if required as part of ongoing management;

3. Review condition of all off-farm assets to ensure fitness for purpose for future conditions;

4. Investigate potential economic and financial impact on scheme productivity; and

5. Provide for a contingency fund for climate change related impacts.

7.2.3 On - Farm

6. Commence increased monitoring of stock drinking water use and stock drinking patterns;

7. Review irrigation water use efficiencies and application techniques as a climate change adaptation strategy;

8. As part of the on-farm asset renewal programme, review asset role and “climate proof “ the replacement asset according to climate change impact predictions;

9. Adapt farm management practices to take into account climate change related impacts; and

10. Adjust irrigation application rates to take into account climate change effects on rainfall and evapo-transpiration.

7.3 Potential Solutions for Adaptation Against Climate Change Impacts

1. Set up monitoring programmes to identify and project more closely climate change impacts to allow for proper planning of projected impacts;

2. Where appropriate replace or renew intake screen cleaning devices with automated devices;

3. For storages involving spillways, review spillway capacities and upgrade capacities to comply with the new national dam safety regulations;

4. Ensure budgets for scheme operations and maintenance are sufficient to cope with any increased costs associated with adapting to climate change;

5. Ensure replacement of all assets take into account likely climate change impacts over the life of the asset; and

6. Undertake a comprehensive review of future water demands coupled with a review of likely availability of water resource in the future and revise scheme level of service accordingly.

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Appendix A: MAF Work Scope

Schedule 1: PROJECT INFORMATION

1. Introduction

New Zealand agriculture and forestry will face a changing climate in the future including warmer temperatures, increased droughts in the east and more intensive, frequent and damaging rainfall events across the country. Land based primary sectors[1] are also likely to benefit from enhanced growing conditions, longer growing seasons and less frost risk, so long as water is available. The growing conditions in New Zealand are changing, as are the requirements for rural water infrastructure. Adapting to a changing climate is becoming a priority.

The overall long-term goals for adaptation in New Zealand as agreed by land based sectors, Maori, local and central government, are to ensure:

- Reduced vulnerability to a changing climate;
- Resilient farms, forests and rural communities;
- Opportunities presented by a changing climate are captured.

Understanding the physical impacts of climate change on rural water infrastructure is important as this underpins many agricultural and horticultural production systems. The larger impacts of a changing climate on rainfall patterns and water resources are excluded from this work. The focus of the work is on the infrastructure itself. The intention is to understand the potential issues and solutions to the physical impacts on climate change on infrastructure.

MAF is interested in understanding the potential impacts of droughts, floods, more intense rainfall events, wind and increased temperatures on rural water infrastructure including smaller community irrigation schemes, stock water races and farm storage. In particular, MAF is interested in the effects on:

- the structural integrity and/or operation of storage areas, dams, spillways, intakes, pipes, irrigation channels, on-farm reticulated systems etc
- increased temperature on water races and any impacts on weed growth or water quality
- sediment and/ or erosion control issues
- changing management or maintenance requirements

Given the range of environmental conditions and schemes across New Zealand, a series of case studies is suggested as a way to illustrate relevant effects, issues and solutions.

2. Service Description

To meet the project requirements, the final outputs should demonstrate an understanding of the likely impacts of climate change on rural water infrastructure, outline key findings, offer a discussion, identify potential solutions and provide recommendations.

The contractor is expected to use the IPCC Fourth Assessment Report findings downscaled for New Zealand.

Detailed climate modelling is out of scope, as is any changes in the availability or quantity of rainfall and/or water resources around the country.

3. Service Requirements

MAF expects the following components to be included within proposals:

- full costings, including key personnel working in the project, with hours and rates identified
- key climate change threats to water infrastructure noted

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[1] Includes all those involved in the land based primary sector (agriculture, horticulture and forestry), essentially the farmers, growers and foresters that rely on the land for their core business

- likely responses of water infrastructure to climate change outlined and implications discussed
- a method to identify any effects or implications that are of particular significance to Māori (for instance values significant to Māori, including land, wetlands and waterways)
- case studies that represent the range of likely schemes and effects across the country
- recommendations for future action

4. Key Deliverables

Key deliverables are:

- A concise report that summarises the impacts of climate change on rural water infrastructure in New Zealand, addressing the matters outlined in the service description. Specifically the work should:
  - Identify representative water infrastructure schemes/structures across the country that will be affected by climate change in a series of case studies.
  - Identify and discuss the impacts that arise from a changing climate affecting water infrastructure, including productivity and economic costs
  - Determine how climate change could or should be factored into water infrastructure management, including any timing issues or advantages that early actions that might return
  - Identify any potential solutions or methods to minimise future costs to managing water infrastructure
  - Use work that incorporates material from the downscaled IPCC Fourth Assessment Report as a basis for the projected effects of a changing climate in New Zealand, although detailed modelling is not required.
- A four to six page summary of the report in plain English
- A fact sheet outlining key impacts of climate change on rural water infrastructure systems suitable for a farmer audience.

5. Opportunities for Maori

No particular opportunities for Māori have been identified at this point in time, although Māori land managers, like other land managers will benefit from this research.

6. Milestones

#	Activity
1	Close Request for Proposal
2	Complete Evaluation *(approx 2 weeks after close of RFP)*
3	Agreement Signed *(approx 4 weeks after evaluation)*
4	Milestone X *(as suitable to respondents proposal)*
5	Milestone X
6	Milestone X
7	Milestone X
8	Project Completion Date – **30 June 2010**

7. Indicative Budget

Less than $100,000, including disbursements, travel or any other incidental costs

8. Reference Material

Respondents may benefit from reviewing the following material available online:

2.1 The EcoClimate Report: Climate change and agricultural production
http://www.maf.govt.nz/climatechange/slm/ag-production/

2.2 Climate change research grants funded by MAF at http://www.maf.govt.nz/climatechange/slm/grants/research/

2.3 Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand http://www.mfe.govt.nz/publications/climate/climate-change-effect-impacts-assessments-may08/index.html

Appendix B: Assumptions or Basis for Capital, Operating and Maintenance Cost Changes

B.1 Basis for Capital Cost Upgrades of Infrastructure

Cost estimates for upgrades to maintain the current levels of flow takes under the varying climate change scenarios have been developed by MWH and in consultation with case study scheme managers or chairmen. The cost estimates also follow the methodology used for the MAF funded report *Comparison of Piped and Open Channel Distribution of Irrigation Water Supplies* (MAF, RITSO 2007). These are outlined in the following sections.

B.1.1 Sources of Cost Estimates

Cost estimates for replacements or upgrades have been supplied by a number of different people or organisations and the basis of the cost estimates have been derived in a number of ways. Primary sources of cost estimates have included:

- Scheme owners and operators
- Designers
- Contractors
- Material suppliers
- Correlation from schemes already constructed.

B.1.2 Additional Cost Estimates for Full Budget Estimation

The following table itemises costs, excluding those for construction, which may contribute a significant portion of any remedial costs due to climate change. The cost estimates are calculated by multiplying the total construction cost by the percentage estimate and are provided as a range of values used for the case study assessments, with numbers varying depending on the scheme location and type.

Table B.1.2: Additional Items and their Cost Estimates for Inclusion in a Full Budget Estimation

Item	Additional Cost Estimates
Design fees	2% to 8%
Surveying	0% to 2%
Legal fees including easements	1% to 4%
Resource consent fees	1% to 10%
Associated studies often for Resource Consents	1% to 5%
Building consent fees and government levies. (Sometimes these can be negotiated down with council under special clauses of the Building Act)	0% to 1%
Contract document preparation	1% to 3%
Contract management and supervision	1% to 5%
Peer reviews of design	1% to 2%
Import duties	0% to 2%
Freight of goods	0% to 1%
Contingency	0% to 15%

B.1.3 Construction Cost Estimation

Establishing quantities and unit costs for remedial construction were derived from:

- Material suppliers
- Designers
- Contractors

- Published data such as the quantity surveyor construction costs handbook, 'Rawlinsons New Zealand Construction Handbook' (published yearly)
- Transposing unit costs from schemes already constructed or rules of thumb.

B.2 Operational Costs

Operational costs are considered to be recurring costs that are required to maintain the long term viabilities of infrastructure. In assessing operational costs for scheme case studies, the following at a minimum is included in the economic assessment.

Table B.2.1: Operational Cost Items for Inclusion in an Economic Assessment

Item	Pipe schemes	Canal schemes
Director fees	X	X
Insurances	X	X
Rates	X	X
Power, telephones, office administration	X	X
Rents	X	X
Easement fees ongoing	X	X
Equipment and sundries	X	X
Transport	X	X
Wages	X	X
ACC and other wage associated costs	X	X
Training costs	X	X
Water supply fees	X	X
Routine valve and farm offtake replacements	X	
Pump maintenance costs	X	
Cathodic protection if required	X	
Pipe lining minor repairs	X	
Valve blockage	X	
Rock lining repairs		X
Canal lining repairs		X
Gate or screen maintenance		X
Weed spraying		X
Vandal damage		X

B.3 Maintenance Costs

Maintenance costs are considered nonrecurring costs that are required to maintain the long term viability of infrastructure. Typical costs may include:

Table B.3.1: Maintenance Costs for Pipe Schemes

Item	Interval
Pipe lining repairs	Infrequent
Jointed pipes seal degradation	Unlikely
Pipe burst requiring replacement	Infrequent
Council or Transit road realignments requiring pipe realignment	Infrequent
Valves, etc	Infrequent
Inspection and material testing	Infrequent
Intake including fish screen repairs	Common

Table B.3.2: Maintenance Costs for Canal Schemes

Item	Interval
Canal rock and lining repairs	Infrequent
Gates and screen damage or replacement	Infrequent
Culvert, drop structures, distribution structure repairs	Infrequent
Intake or fish screen repairs	Common
Canal or head pond sediment removal	Common
Storm damage from excessive inflows	Infrequent
Spillway repairs	Infrequent

B.4 Cost Sensitivity and Risk

Assessing the risk appetite that scheme owners are willing to accept from the impacts of climate change can significantly affect the cost of remedial actions. This includes the cost for construction, operation and maintenance costs, and the replacement period between parts of the scheme infrastructure as it wears out due to normal operation or as a result of climate change. Risk is not discussed in detail in this report, but an inherent assumption is made that owners or developers will assess it at all levels and for all components of a scheme whether specifically, or by intuition in any decision making process.

Appendix C: Irrigation Scheme Case Studies

Waimakariri Irrigation Scheme

The Waimakariri Irrigation Limited (WIL) scheme in Canterbury was constructed after many initiatives and proposals from the 1970s. It supplies water from the Waimakariri River to the upper plains area between Rangiora and Oxford north of the river, up to the Ashley River.

The Irrigation Scheme

- An irrigation scheme comprising river intake, main race and distribution races supplying pastoral and mixed cropping land.
- The scheme supplies 18,000 hectares and was opened in 1999.
- Water take of 10.5 m³/s is sourced from the Waimakariri River with an additional 2.1 m³/s for stockwater, a total of 8% of mean river flow.
- The scheme includes a buffer pond and numerous on farm storage ponds.
- It serves 225 shareholders.

The present Waimakariri scheme became operational in 1999, with the most recent upgrade in 2002 increasing the scheme area from 14,000 to 18,000 hectares. The scheme is operated by a company, with 225 shareholders holding a total of 126,000 shares, with the shares based on a water allocation.

The scheme has consent to take up to 10.5 m³/s of irrigation water from the Waimakariri River, with an additional 2.1 m³/s for stockwater. The water is distributed through a main head race between the Waimakariri and Ashley Rivers, with distribution races mainly running towards the coast. WIL distribute the stockwater through their system on behalf of the Waimakariri District Council. This was not assessed as part of this study.

There is about 250 km of irrigation races and 800 km of stockwater races, and it takes 48 hours for water from the river intake to reach the furthest property turnouts. Because of the long travel times and hence difficulties in varying water supply, the scheme operates on a continuous supply basis.

The supply is run-of-river, with a gravity race reticulation network. Like most irrigation schemes, it resembles an arterial system in that race sizes get smaller as side races are fed and water supplies are made. All of the races have been designed to carry the volumes required to supply the shares they service. An intake, just downstream of the Waimakariri Gorge, takes water from the Waimakariri River via an intake structure to the settling ponds. A main race (canal) traverses the river terrace in the direction of the river until it crosses under Thongcaster Road and across the plain. A buffer pond helps to regulate flow through the main race and provide a small amount of storage. Numerous distribution races feed the rest of the scheme.

Figure 1: Main Race

SCHEME COMPONENTS

Details of the scheme components are shown in the following table:

Scheme Component	Description/Details	
Intake structure	Incorporating the screen (boat) and the associated headworks structure and intake gate. A stilling basin leads to the start of the main race.	
Settling ponds	Settling ponds are located approximately 300 metres downstream of the intake structure.	
Main race(s)	MR1 to MR13 totalling approximately 35 kilometres. The main race gates are for 1200 mm diameter culverts.	
Main race syphon (Eyre River)	Two syphons cross under the Eyre River. These are 1500 mm diameter Aluflo and approximately 180 metres long.	
Buffer pond	The buffer pond allows for approximately 2 hours of storage and has a volume in the order of 80,000 cubic metres.	
Main Races	Length (m)	Race capacity (m^3/s)
MR1	6,788	12.4
MR2	4,316	11.9
MR3	1,138	10.4
MR4	1,883	7.6
MR5	998	7.2
MR6	1,154	7.1
MR7	1,355	6.6
MR8	2,289	3.9
MR9	1,908	2.9
MR10	1,330	2.7
MR11	3,698	2.0
MR12	2,159	1.3
MR13	5,740	0.4
TOTAL	**34,756**	
Distribution races		
R1	6,100	0.20
R2	13,950	0.73
R3-1	5,450	2.81
R3-2	1,070	2.56
R3-3	2,860	2.34
R3-4	690	1.84
R3-5	3,570	1.66
R3-6	2,300	1.44
R3-7A	5,990	1.31
R3-7B	4,530	1.07
R3-8	490	1.02
R3-9	3,080	0.95
R3-10	1,390	0.52
R3-11	440	0.45
R3-12	1,670	0.23
R3-13	1,770	0.12
R3A	7,250	0.10
R3C	4,740	0.10
R3D	5,340	0.18
R3E-1	5,150	0.50
R3E-2	9,790	0.15
R3F	8,300	0.29
R3G	2,130	0.02
R3H	2,570	0.13
R3I	830	0.05
R3I-1	5,750	
R3J-1	8,200	0.09
R3J-2	5,300	0.07
R3J-3	7,260	0.07
R3J-4	2,090	0.08
R3K	370	0.07
R3L	5,300	0.09
R3M	8,470	0.29
Egans Road Ext	1,650	0.11
R3N	3,000	0.05
R3P	750	0.14
R3Q	700	0.02
R4	3,510	0.16
R5	6,210	0.13
R6	1,740	0.12
R7	5,670	0.15
R8-1	6,960	0.43
R8-2	3,120	0.19
R8A	2,810	0.06
R9	930	0.03
R10-1	10,560	0.23
R10-2	2,200	
R10-4	2,200	
R11-1	3,090	0.14
R11-2	950	0.07
R11A	3,550	0.06
R12	14,640	0.22
CD1	1,220	NA
CD2	540	NA
CD3	400	NA
TOTAL	**220,590**	
Distribution race gates	Approximately 50 rectangular type gates which cover culverts ranging in size from 300 to 1050 mm diameter.	
Culverts/headwalls	500 plus culverts ranging in size from 300 to 2100 mm diameter and associated headwalls.	

Figure 2: Existing irrigation pump house

The existing scheme operating and maintenance costs (from the Waimakariri Irrigation Ltd Annual Report, year end June 2009) are:

Scheme Component	Operation/Maintenance Costs
Operation expenses	$69,000 at $3.80/ha/yr
Repairs and maintenance	$152,000 at $8.40/ha/yr
Total annual O&M costs	**$221,000 at $12.20/ha/yr**

Climate Change	Effect
Average rainfall increased but less snow fall and shorter snow melt season	Potentially higher river flows in winter and early spring but possibly lower flows in summer may lead to increased pressure on water resources at times.
Increased risk of drought	Increased frequency and durations of very low river flows may at times increase pressure on water resources. Waimakariri River flow could potentially maintain close to its current summer and autumn flow regimes, but pressure may come on the resource as other lowland water sources face increased low flows or low groundwater levels.
Increase in average temperature; Increase in very hot days	Increased temperatures in river water contributing to higher risk of nuisance algae development and increased variability on DO and pH regimes, placing river ecology under increased stress. Potentially higher maintenance costs for irrigation scheme infrastructure due to increased corrosion. Potentially higher risk of invasion by unwanted organisms (but possibly reduced risk associated with didymo).
Increased frequency of heavy rain events	Increased sediment loads in the Waimakariri River and possibly decreased or static maintenance costs for scheme.
Increased summer water deficit for un-irrigated land	Increased water demand for land currently in Scheme.
Increased windiness	Coupled with an increase in temperature this could lead to an increase in erosion of topsoil.

CLIMATE CHANGE EFFECTS

While the mean annual rainfall at WIL is projected to decrease slightly, the rainfall at the headwaters of the Waimakariri River shows an overall increase, particularly in winter and spring. This is likely to be counteracted to some extent by the reduction in snow in the Waimakariri catchment, of up to 45% at low elevations (1500m) in 2090, which will impact on seasonal river flow in spring and early summer. This may lead to increased pressure on water resources in summer. An increase in the frequency of extreme rainfall events is projected, which will lead to increased sediment loads in the river.

Temperatures in Canterbury are projected to increase by 0.9°C above current levels by 2040 and 2.0°C by 2090, and the number of very hot days (over 25°C) is projected to increase by 12 to 20 days by 2090. Frosts are expected to decrease, with up to 20 fewer frost days by 2100. There is also a projected increase in the frequency of drought conditions, which suggests an increased demand for irrigation water.

It is projected that the westerly component of wind in Canterbury will increase by 10% within the next 50 years. Wind typically plays an important role in evapo-transpiration, and as a result moisture loss at WIL is likely to increase.

The temperature of the river water is projected to increase with rising air temperatures, particularly in the middle and lower reaches which will be susceptible to warming in summer due to the width of the river that is too wide to receive shading of the riverbed by vegetation. The 250 km of irrigation races and 800 km of stockwater races will also be susceptible to warming. The increase in temperature is likely to contribute to development of nuisance algae growth and associated water quality effects. Didymo has not yet been observed at nuisance levels on the Waimakariri River. The warmer conditions may reduce its susceptibility in the future.

IMPACTS ON INFRASTRUCTURE AND POTENTIAL RESPONSE OPTIONS

Potential adverse effects associated with summer heating and reduced summer flows in the Waimakariri River may contribute to the already intense debate around a sustainable residual flow regime. It may also potentially lead to reduced availability of water for irrigation at critical times unless more storage can be provided. The projected increases in potential evapo-transpiration deficits (PEDs), a measure of drought or water deficit, are 12-30%.

The increase in algae and nuisance weed growth is expected to result in increased clogging of screens and the requirement for weed cleaning. There may also be clogging of service lines and spray heads, and the need for increased canal sediment cleaning.

Scheme Component	Impact	Response Options	Cost Implications	
Intake screens	Weed and debris ingestion prevention Sediment erosion minimisation	Install screens, assumed filtration gallery	Operation cost $0.5/ha/yr	
Sediment cleaning	Increased canal sediment cleaning	Increased removal of sediment	$0.50/ha/yr	
Weed cleaning	Increased weed growth and cleaning	Increased removal of weed	$1/ha/yr	
On farm irrigation	Canal cleaning, damage and clogging to service lines and spray heads, etc	Increased operation and maintenance costs on farm	$10/ha/yr	

Figure 3: Intake structure

FEEDBACK FROM THE SYSTEM OPERATORS

Weed growth is a primary concern to the system operators as they are starting to experience an increase in weed clearing requirements. It is predicted that excess take capacity on the 5mm screens may be required. Increased sedimentation will require more canal cleaning, although there are not anticipated to be any costs over and above the weed cleaning costs. Didymo is of great concern although has not been observed at nuisance levels in the Waimakariri River yet.

Flooding is not a significant area of concern for the scheme operators, although cross flow into the canal where the upstream catchment is large may result in additional repair costs.

The operating life of pumps and other mechanical equipment is expected to reduce due to wear and tear on equipment, with an increase in annual servicing requirements. Similarly, on farm operating and maintenance costs will increase due to wear and tear of irrigation system infrastructure.

The annual operating and maintenance costs are anticipated to increase as a result of climate change to the following levels:

Scheme Component	Operation/Maintenance Costs
Operating expenses	$105,000 at $5.80/ha/yr
Repairs and maintenance	$331,200 at $18.40/ha/yr
Total annual O&M costs	**$436,200 at $24.20/ha/yr**

ECONOMIC AND PRODUCTIVITY ASSESSMENT

The land use within the scheme is mostly pastoral and mixed cropping, but no information on production or the economic benefits of the irrigation has been obtained for this study.

The scheme operates with each shareholder taking their allocated water according to a rotation. Each share entitles the irrigator to 0.075 litre/second/hectare, and a shareholder may hold up to 9 shares per hectare (0.675 L/sec/ha). All the supply is allocated and there is no spare capacity in any of the races. Shares can be transferred, but there are restrictions on these transfers.

There is potential competition and future constraints to the scheme, given it is sourcing from a major regional river in a generally water short region. There is also another large irrigation scheme (Central Plains) planned, which will draw water from the Waimakariri River, upstream of this scheme's intake.

The projected increases in potential water deficits from a changing climate are significant, and supply is constrained by the physical size and layout of the race network. There is no practical way of marginally increasing the supply, with any excess water being by-washed from the race network.

The scheme provides a significant level of security to farms in the area and flexibility of land use. It is likely to be retained in its present form and operational functions with climate change, and be utilised for the advantages it gives. There are many on-farm adaptations that could be undertaken, which would be more cost effective than an upgrading of the scheme infrastructure. The irrigation allows better management of soil moisture levels to improve productivity, and on-farm improvements in soil health and soil structure, local retention of rainfall and better utilisation of the water supplied would all assist in adapting to a climate of more extremes and prolonged droughts. There is also plenty of opportunity to alter existing land uses in this scheme area and grow other crops.

The operation and maintenance costs of the scheme are relatively low, currently at around $12/ha/year. The major expense is the capital development, and operating costs are spread over a large area of land. The largest additional cost is likely to arise from extra clearing of races and irrigation equipment, with an estimated addition of $10/ha/year. Overall the operation and maintenance costs could double, to around $24/ha/year. However, these costs are small relative to on-farm costs, even given the less intensive land uses in this scheme compared to horticultural schemes.

The economic impacts from altering land uses and growing other crops cannot be predicted, with future farm returns depending on many other influences, not least market prices and the costs of farm inputs.

Figure 4: Existing irrigation pump offtake

Figure 5: Storage pond

FOR MORE INFORMATION

- Report on *Impacts of Climate Change on Rural Water Infrastructure*, prepared by MWH for MAF, June 2010

Appendix C: Irrigation Scheme Case Studies

CLIMATE CHANGE IMPACTS ON RURAL WATER INFRASTRUCTURE: CASE STUDY 1

Kerikeri Irrigation Scheme

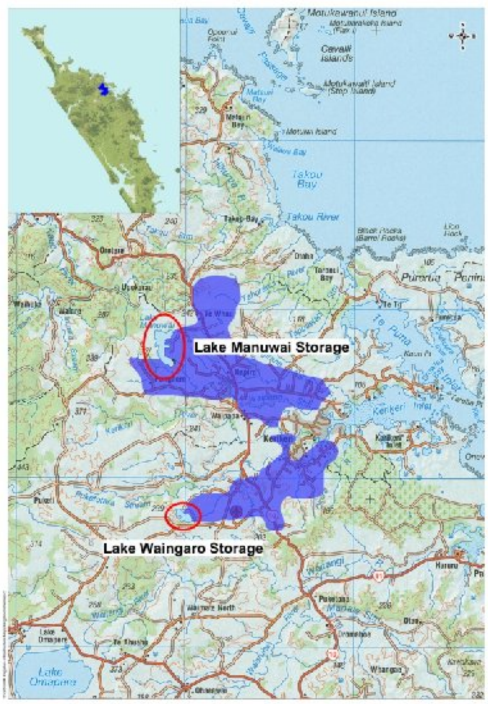
The Irrigation Scheme

- A storage, gravity feed, pumped scheme
- The scheme supplies 2,800 hectares and was opened in 1983
- Water is sourced from two lakes, the Waiwhakangarongaro Stream (Lake Waingaro) and Waipapa River (Lake Manuwai)

Facts and Figures on the Reservoirs

Waingaro Dam (Southern Reservoir)
Grid coordinates: 2,591,170E, 6,659,580N
Storage capacity: 4.8 Mm³

Manuwai Dam (Northern Reservoir):
Grid coordinates: 2,590,140E, 6,668,850N
Storage capacity: 8.5 Mm³



The Kerikeri Irrigation Scheme in Northland is a cooperative shareholder scheme that supplies water to land that is mostly used for horticultural crops. The scheme covers rolling land and utilises the winter runoff from two separate small stream main catchments. The water is stored in two reservoirs at the upper end of the two halves of the scheme, the Southern Reservoir Lake Waingaro and the Northern Reservoir Lake Manuwai.

The reservoirs are located high in the catchments to minimise the diversion and spillway costs and to enable gravity feed irrigation supply. The two storages supply water to approximately 2,800 hectares of mostly horticultural land. In addition, Kerikeri Irrigation Company Ltd is contracted with the Far North District Council to supply the township of Kerikeri with up to 2 million cubic metres of water annually. Recreation is common at Lake Manuwai, especially yachting and fishing. The storages act as a venue for yachting clubs, rowing clubs, swimming, canoeing, and trout fishing.

The scheme was designed for intensive horticulture, and the economic benefits of the scheme were based on citrus and sub-tropical fruits.

Kerikeri Irrigation Scheme includes approximately 120 kilometres of pipelines, and numerous smaller infrastructure to service approximately 350 shareholders, of which 2,300 hectares is for horticulture, 300 hectares for agriculture, and the remainder for lifestyle farms.

This case study allows storage, spillways, pipes, valves, and on-farm systems to be assessed in a sub-tropical area where flood and intense rainfall events are common.

Figure 1: Manuwai Reservoir

SCHEME COMPONENTS

The scheme is primarily a diversion and dam storage supply scheme. Details of the scheme components are shown in the following table.

Scheme Component	Description/Details
Southern Reservoir – Lake Waingaro	
Catchment area (including diversions)	645 hectares
Volume of compacted earth in dam	720,000 cubic metres
Dam height & width	33 metres high & 400 metres wide
Live storage volume	4.8 million cubic metres
Reservoir area (at top water level)	44 hectares
Maximum water flow	660 litres per second
Service spillway	Semi-circular spillway discharging to a concrete chute channel and impact stilling basin
Auxiliary spillway	Grassed spillway 50 metres long (located close to the Puketotara Diversion works)
Culvert/pipelines	Concrete culvert through dam (used for stream diversion during construction) and carries the scour pipe and service pipework to the irrigation scheme
Puketotara Diversion	Earth embankment 10 metres high and 50 metres long across the Puketotara Stream. An unlined canal transfers the water into the western end of Lake Waingaro.
Northern Reservoir – Lake Manuwai	
Catchment area	575 hectares
Volume of compacted earth in dam	400,000 cubic metres
Dam height & width	28 metres & 300 metres wide
Live storage volume	8 million cubic metres
Reservoir area (at top water level)	122 hectares
Maximum water flow	600 litres per second and 420 litres per second to Waipapa Stream
Service spillway	Semi-circular bellmouth spillway discharging to an impact stilling basin via a concrete lined channel chute
Auxiliary spillway	Grassed spillway into a grass gully adjacent to the right abutment
Culvert/pipelines	Concrete box culvert through dam (used for stream diversion during construction) and carries the service pipework to the irrigation scheme and for the small hydroelectric generating plant at the toe of the dam
Pump Stations	
Dam 8	Sandys Road
SH10	SH10
Onekura Road	Onekura Road
Pungare Road	Booster
Sandys Road	Booster
SH10	Booster
Takau Bay	Booster
Intake No.6	Booster
Cross Roads	

Figure 2: Manuwai Pump Station

Minor Dams			
Onekura Road Weir		Intake No 6	
Waipapa Stream Northern Branch		Whangai Diversion Weir	
Waipapa Stream Weir B		Puketotara Diversion	
Diversion Tunnel Pipes and Ancillary components			
South Dam 4		North Dam 8	
Pipes Distribution			
Size (mm)	**Length (m)**	**Size (mm)**	**Length (m)**
32	10,592	250	1,346
50	31,695	300	5,772
65	147	375	3,253
80	13,026	425	78
100	11,931	450	736
125	724	525	770
150	18,764	600	7,950
200	12,032		

The existing scheme operating and maintenance costs supplied by the scheme are:

Scheme Component	Operation/Maintenance Costs
Dams maintenance	$42,094 at $18/ha/yr
Pumps/pipelines/meters maintenance	$97,048 at $42/ha/yr
Total annual O&M costs	**$138,000 at $60/ha/yr**

CLIMATE CHANGE EFFECTS

A reduction in rainfall at the Kerikeri Scheme is projected during the winter and spring months, which will reduce the catchment supply to the reservoirs. An increase in the intensity of rainfalls may increase surface runoff to the reservoirs during storm events. However, temperatures are projected to increase by 0.9°C above current levels by 2040 and 2.1°C by 2090. As a result, evapo-transpiration rates will increase and the overall yield from the catchment is likely to decline. Evaporation from the storage lakes would also be greater with higher ambient temperatures.

Average water temperatures in the reservoirs are expected to increase approximately in line with average air temperatures. Combined with increased sediment and nutrient inputs during periods of heavy rainfall, this may increase the likelihood of nuisance algae blooms, weeds, pest fish or other unwanted organisms.

Climate Change	Effect
Average rainfall decreases, particularly in winter and spring	Lower stream flows and potentially more rigorous residual flow requirements for source streams. Low stream flows in winter and spring and less water available to put into storage.
Increased risk of drought	Increased frequency and durations of very low stream flows may at times increase pressure on water resources and stream ecology.
Increase in average temperature; Increase in very hot days	Increased temperatures in the lakes contributing to higher risk of nuisance algae blooms, weeds, pest fish or other unwanted organisms. May contribute to increased variability on DO and pH regimes. Potentially higher maintenance costs for irrigation scheme infrastructure due to clogging of screens and increased corrosion. Increased temperatures in source streams with potentially adverse effects on stream ecology.
Increased frequency of heavy rain events	Increased sediment and nutrient inputs to the lakes contributing to higher risk of nuisance algae blooms or weeds. An increase in the frequency of large floods may lead to re-evaluation of design parameters for storage lakes.
Increased summer water deficit for un-irrigated land	Increased water demand for land currently in the Scheme.

IMPACTS ON INFRASTRUCTURE AND POTENTIAL RESPONSE OPTIONS

The Northland region has long dry periods and seasonal water deficits. The projected increases in potential evapotranspiration deficits (PED), a measure of drought or water deficit, at the Kerikeri scheme are 20-40%. The seasonal supplies to the storage reservoirs will reduce, while seasonal irrigation demand will increase.

The higher rainfall intensities and storm runoff is expected to have implications for the flood flow spillways of the dams and flood bypass facilities.

The existing scheme, of dams and piped reticulation, does cover most of the catchment below the dams, and there would, therefore, be little other demand for irrigation water in competition with the scheme. However, the scheme supplies water to the township of Kerikeri, and increases in domestic urban demand would compete with the horticultural irrigation demand.

Figure 3: Manuwai Dam (downstream side)

Scheme Component	Impact	Response Options	Cost Implications	
Dam Structures	Lower operating levels	Increased observation and maintenance	Operation cost $1/ha/yr	
	Lake weed growth	Likely increase in off take screen capacity and mechanical screen cleaner	$400,000	
	Increased flooding means reservoirs may fill easier	Nil	Nil	
	Increased droughts	Lead to less dam spills	Nil	
	Temperature increase	Land use change and possible capacity increases in reservoir needed	Nil	
Dam Spillway	Increased flood flows. Increased focus on dam failure, increased emergency planning.	Increased spillway capacity required	Once at 15% of dam cost at $1,400,000	
Pump Stations	Reduced pump life through increased pump use due to increased demand use patterns.	Increased maintenance and reduced life	5% life expectancy reduction. Total value of $1.3M with 20 year life expectancy, $1.50/ha/yr.	
Pipe Network	Reduced pipe life span due to cracking of pipes due to drought shrink and wet ground expansion.	Increased pipe repairs	20% of current budget at $4/ha/yr	
	Increased operation and maintenance costs due to drought. Requires increased workload.	Increased labour	20% of current budget at $4/ha/yr	

FEEDBACK FROM THE SYSTEM OPERATORS

Kerikeri Irrigation Company is very concerned about the potential impacts of climate change. Although flooding will increase the ability to fill reservoirs, it will also require increased spillway capacities. Changes in wet/dry patterns will lead to more ground movement (shrink swell) which will increase pipe cracking and hence maintenance costs.

The temperature increases projected at Kerikeri may lead to land use change, and existing storage capacities may be too little. The increased temperatures may also result in more weed and screens may require replacement. Increased demand on the reservoirs is expected to reduce pump life.

The droughts that are projected to occur may mean less dam spills occur. However droughts generally result in more work for operators, and therefore one impact is likely to be a requirement for more labour.

The annual operating and maintenance costs are anticipated to increase as a result of climate change to the following levels:

Scheme Component	Operation/Maintenance Costs
Dams maintenance	$43,700 at $19/ha/yr
Pumps/pipelines/meters maintenance	$115,000 at $50/ha/yr
Total annual O&M costs	**$158,700 at $69/ha/yr**

ECONOMIC AND PRODUCTIVITY ASSESSMENT

The economic evaluation undertaken for the scheme prior to construction included changes in land use, given the size and variations in land uses throughout the scheme area. An economic optimum size was determined, and reticulation too far outside areas planted in orchard at the time was considered uneconomic. The scheme was expensive because of the cost of constructing the large dams of the storage reservoirs, and the return from the scheme was sensitive to produce prices and market development (for citrus juice in this case). There was a balance between a scheme large enough to justify the dam constructions and scheme reticulation, while still having a market (at assumed prices) for the quantities of fruit that would be produced.

The dependence on seasonal storage means there are no practical marginal adjustments to scheme capacity or supply rates. Raising the dams to increase storage capacity would involve major engineering works and difficult retro-fitting construction. Additional new storage dams may be more cost effective, if scheme capacity was to be increased. However, the flow capacity of the pipe reticulation network would remain a constriction on increased daily supplies.

Upgrading the scheme infrastructure would be a complex and demanding exercise, and involve additional storage. The landowner agreement and consenting issues would be difficult, given the size of the scheme and the likely constraints on water use with reducing low flows due to higher temperatures and longer droughts.

On-farm adaptation is expected to be the likely response as temperatures increase and droughts intensify. This would result in a reversal of the productivity gains of the irrigation scheme, with a progressive loss of production benefits, while operational costs are likely to increase. Increased sediment input from more frequent floods and greater water weed growth could increase operational costs, while larger flood flows would have impacts on the spillway capacity of the dams. Any additional pumping to maintain supply pressures would also impact on operational costs.

Changing crop varieties or land uses, and on-farm measures to maintain soil moisture and effectively use on-site rainfall may help in maintaining productivity. However, the flexibility and security provided by the existing irrigation scheme would be lessened in concert with increased water deficits from climate changes.

The estimated additional costs due to climatic changes include about $1.5 million to increase the dam spillway capacity, and close to $0.5 million for increased screen capacity and mechanical cleaning of the screens at the lake outlets. There would be effects on pump life and the distribution network from additional weed intake, and from greater running times and higher pressure pumping. The estimated additional operating costs are very small on a per hectare basis, and would generally be small proportions of current operating costs. The annual costs may increase from about $50 to $60/hectare. By way of contrast, the annual production costs for a citrus orchard can be from $10,000 to $15,000 per hectare, with some of these costs depending on the fruit yield.

While there may be significant dam and pump costs, they are spread over a large area of intensive horticultural land uses, and per hectare or property costs are likely to be small in comparison to other costs of horticultural production. Returns would be much more affected by market price variations, which could themselves be directly or indirectly affected by the impacts of climate changes on national or global production.

Figure 4: Waingaro Dam

FOR MORE INFORMATION

- Report on *Impacts of Climate Change on Rural Water Infrastructure*, prepared by MWH for MAF, June 2010

Appendix C: Irrigation Scheme Case Studies

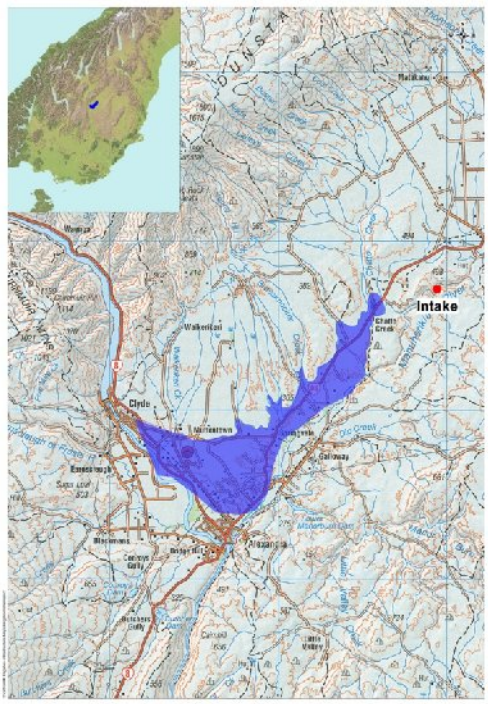
CLIMATE CHANGE IMPACTS ON RURAL WATER INFRASTRUCTURE: CASE STUDY 5

Manuherikia Irrigation Scheme

The Manuherikia Irrigation Scheme is located just north of Alexandra and east of Clyde in Central Otago. It is an old scheme which supplies water to about 285 properties, with an irrigated area of about 2,250 hectares. The distribution is by gravity through an open race network.

The Irrigation Scheme

- A storage and gravity feed scheme supplying irrigation water to land with varying uses including arable farming, horticulture, viticulture and lifestyle properties.
- The scheme supplies 2,245 hectares and was opened in 1922.
- Water is sourced from the Manuherikia River and Chatto Creek, with river take at 2,830 L/s.
- Storage of 10.4 Mm^3 is provided at Falls Dam, of which Manuherikia scheme has 35%.
- The scheme serves about 285 shareholders.



The scheme consists of a main race which draws water from the Manuherikia River and utilises storage from the Falls Dam located on the upper reaches of the Manuherikia River. The supply is supplemented by the Borough race system which is supplied from a local stream (Chatto Creek).

This irrigation scheme was the first in Central Otago that was not founded on the remains of mining enterprise, with the main race system being constructed specifically for irrigation purposes. However, the scheme does incorporate some mining races and early water rights. Construction of the scheme commenced in 1917 and was substantially completed in 1922. In 1936/37 a troublesome section of concrete-lined race in the Ophir Gorge headworks was replaced by a 1,580 m long 1.8 m x1.2 m tunnel. The Borough race was constructed in 1864 as a mining race and was acquired by Alexandra Borough for a town supply. In 1922 it was acquired from the Borough in exchange for delivery of 0.057 m^3/s at the Borough boundary.

Falls Dam on the Manuherikia River approximately 40 kilometres upstream of the Manuherikia main intake provides storage for the Omakau, Blackstone Hill, Manuherikia, and Galloway irrigation schemes. The Manuherikia main race draws water from the Manuherikia River at Ophir Gorge. The flow is carried through an elaborate series of headworks to the Chatto Creek syphon. From Chatto Creek the main race travels to Springvale and then moves in a westerly direction towards Clyde township. Numerous distribution races extend from the main race in a southeast direction parallel to one another.

The Borough race extracts flow from Chatto Creek and travels in a southwest direction to irrigate the terrace above the Manuherikia River. The Borough race is also able to utilise water which has been bywashed from the Manuherikia main race, resulting in more water being sold from the Borough race than is put in at Chatto Creek.

Figure 1: Main Race

SCHEME COMPONENTS

The scheme is primarily a tunnel and open race network. Details of the scheme components are shown in the following table.

Scheme Component	Description/Details
Falls Dam	Rock fill dam constructed in 1935, and raised in 1955. 33.5 metres high. 10.4 million cubic metres of storage capacity. Discharges to the Manuherikia River from where Blackstone Hill, Omakau and Manuherikia schemes take water directly and the Galloway scheme pumps. While Manuherikia has a 35% share of the storage in Falls Dam, at times of low river flows the schemes all ration by the same amount.
Manuherikia headworks	The first 5.5 kilometres of the Main Race is considered to be headworks. The initial section of the race runs through the gorge over extremely rough terrain, and consists of: Intake structure 470 m long tunnel (150 m concrete lined) Silt trap 436 m concrete lined sidling race Concrete pipe culvert/lined race 1,580 m tunnel (370 m concrete invert and sides) 150 m steel flume on wooden trellis (Chinky Gully) 1,700 m open race 550 m long syphon (Chatto Creek) The scheme draws up to 2.36 m^3/s from the river at Ophir Gorge.
Main Race	The Main Race draws water from the river at Ophir Gorge. The flow is carried through an elaborate series of headworks to the Chatto Creek syphon. From Chatto Creek the Main Race travels to Springvale and then moves in a westerly direction towards Clyde township. The system comprises 72.3 kilometres of main races, 35.6 kilometres on the Manuherikia main system, and 43.8 of distribution races. Within these races are 2.8 kilometres of syphons and 2 tunnels totalling 2,050 metres.
Chatto Creek intake	The Borough Race abstracts up to 0.17 m^3/s from an inlet on Chatto Creek, approximately 6 kilometres upstream of its confluence with the Manuherikia River.
Borough Race	The Borough Race abstracts flow from Chatto Creek and travels in a southwest direction to irrigate the terrace above the Manuherikia River. 600 m^3/hr of water is taken from Chatto Creek. At several points along the race, water is fed in from the Main Race. This allows the capacity of the Borough Race to be raised to 1,500 m^3/hr at these points.
Distribution races	Numerous distribution races extend from the main race in a southeast direction parallel to one another.

Figure 2: De-silter at the outlet of Tunnel No. 1

The scheme has been improved substantially since originally constructed and then following takeover by the Manuherikia Irrigation Co-operative Society in the early 1990's. This includes substantial benching of races and re-alignment of leaking sections. More recently there has been major piping works in the headwaters gorge and piping of smaller races near the extremities of the scheme, along with upgrading structures, race outlets and measuring devices. Annually $70,000 is budgeted for this type of non-routine maintenance.

The Co-operative are currently undertaking feasibility studies to investigate supplying all or part of the existing schemes (with some expansion areas) with a piped scheme from Lake Dunstan. This is being assessed in conjunction with the Galloway Scheme, Otago Regional Council and Central Otago District Council.

The existing scheme operating and maintenance costs supplied by the scheme are:

Scheme Component	Operation/Maintenance Costs
Scheme operation contract	$185,000 at $82/ha/yr
Maintenance	$75,000 at $33/ha//yr
Falls Dam expenses	$3,500 at $1.50/ha/yr
Total (2009)	**$263,500 at $117/ha/yr**

Climate Change	Effect
Average rainfall increased across all seasons	Higher river average river flows across all seasons will provide benefits for instream ecology and at times reduce pressure on the water resource.
Increased risk of drought	Increased frequency and durations of very low river flows may at times increase pressure on water resources.
Increase in average temperature; Increase in very hot days	Increased summer temperatures in the Manuherikia River contributing to higher risk of nuisance algae growth and increased variability on DO and pH regimes, placing stream ecology under increased stress. Potentially higher maintenance costs for irrigation scheme infrastructure due to clogging of screens and increased corrosion. May also increase the risk of invasion by other unwanted organisms (but possibly reduced risk associated with didymo).
Increased frequency of heavy rain events	Increased sediment loads in the Manuherikia River and possibly increased maintenance costs for scheme.
Increased summer water deficit for un-irrigated land	Increased water demand for land currently in scheme.

CLIMATE CHANGE EFFECTS

The mean annual rainfall over the Manuherikia catchment area is projected to increase across all seasons, with up to 20% over the winter months by 2090. Similarly, there will be an increase in the frequency of extreme rainfall events. However annual snow falls at high elevations of the catchment (1600 to 1800 m) are expected to decrease considerably, by 20% in 2040 and 40% in 2090. This will result in a marked change in seasonal river flow in spring and early summer when snowmelt traditionally boosts flows.

Temperatures are projected to increase by 0.9°C above current levels by 2040 and 2.0°C by 2090, coupled with the number of very hot days (over 25°C) increasing and number of frosts decreasing. The number of drought days is not projected to increase markedly.

The temperature of the river water is projected to increase with rising air temperatures, and water in the Manuherikia main race, which is mostly unshaded, is expected to be susceptible to summer heating.

IMPACTS ON INFRASTRUCTURE AND POTENTIAL RESPONSE OPTIONS

Projected increases in mean rainfall in the Manuherikia catchment area will provide benefits for instream ecology and reduce pressure on the water resource. The increase in extreme rain events is likely to lead to increased sediment yields from erosion prone areas, and the requirement for increased sediment cleaning.

The projected increase in the drought risk in the area is expected to increase the demand for irrigation water, particularly in the dry summer months when the river flow is low.

The consequence of the increased water temperatures and CO_2 levels is likely to contribute to development of nuisance weed and algae growth. This is expected to result in increased clogging of screens and the requirement for weed cleaning.

The rate of supply of water is constrained by the existing capacity of the race network, and increasing daily supply rates would require a major upgrade of the irrigation reticulation system. The increases in seasonal water deficits from the projected climate changes are a small proportion of the potential evapo-transpiration deficit (PED) in the scheme area, given the large existing deficits in the area, at approximately 10%. The projections also indicate an increase in catchment runoff and inflows into the storage dam over winter and spring. Depending on the operational use of the dam storage, and the flexibility of supply from the storage reservoir, this increase in over-season inflows could provide additional seasonal supply to match increased seasonal demand.

Scheme Component	Impact	Response Options	Cost Implications	
Intake Screens (not existing)	Weed and debris ingestion prevention Sediment erosion minimisation	Install screens, assumed filtration gallery	New screen $600,000 Operation cost $4/ha/yr	
Sediment cleaning	Increased canal sediment cleaning	Increased removal, double current	$15/ha/yr	
Canal maintenance	Flood damage	Increased repairs	$5/ha/yr	
Weed cleaning	Increased weed growth and cleaning	Increased removal, double current	$15/ha/yr	
On farm irrigation	Canal cleaning, damage and clogging to service lines and spray heads etc	Increased operation and maintenance costs on farm	$10/ha/yr	

Figure 3: Borough Race

FEEDBACK FROM THE SYSTEM OPERATORS

In recent years the scheme operators have become increasingly aware that impacts of climate change may have risks to the scheme in the future. It is expected that regional pressure will drive the scheme to use water more efficiently which may potentially result in a change of infrastructure to piping.

Land use change to dairy or other intensive uses in the upstream catchments may increase nutrient loadings and potentially weed growth. Weed growth is a primary concern to the system operators as they are starting to experience an increase in weed clearing requirements. Increased sedimentation will require more canal cleaning, although there are not anticipated to be any costs over and above the weed cleaning costs. Didymo is of great concern although has not been observed at nuisance levels in the Manuherikia River yet.

Flooding is an area of concern for the scheme operators, due to the difficulty in accessing the tunnel intake and the risk of damage to the gorge races and piped sections from high waters. Automation of the intake gates, which is programmed into the schemes's forward works programme, will decrease the risk of damage. Cross flow into the canal where the upstream catchment is large may result in additional repair costs.

The annual operation and maintenance costs are anticipated to increase as a result of climate change to the following levels:

Scheme Component	Operation/Maintenance Costs
Scheme operation	$283,000 at $126/ha/yr
Maintenance	$85,300 at $38/ha//yr
Falls Dam expenses	$3,500 at $1.50/ha/yr
Total	**$371,800 at $166/ha/yr**

ECONOMIC AND PRODUCTIVITY ASSESSMENT

There have been various proposals to upgrade and extend the scheme. A major proposal was shelved in the 1970s, because of concerns about the economics of irrigation in the area, following the construction of the Maniototo scheme, to the east of the Manuherikia Valley.

At present there is a proposal for a new scheme to irrigate dryland located east of Clyde township using water from Lake Dunstan at Dairy Creek. The Manuherikia Irrigation Co-operative Society holds a water permit for 4.53 cumecs of irrigation water from this location. The capital costs would be around $5,000 to $6,500 per hectare, plus operating costs of around $1,000/ha, including loan repayment charges. There would also be on-farm irrigation costs, of around $2,000 to $3,000 for piped reticulation.

No cost-benefit analysis has been carried out on this proposal, but a comparison of land valuations for different land uses has been undertaken. The area is mostly large farms with extensive sheep grazing, large scale viticulture and some lifestyle block developments. The irrigation would allow other more intensive land uses, but development of the land into intensive land uses would also be necessary for the scheme to be economic. This scheme, thus, requires a high degree of land intensification, and hence subdivision and changes in ownership.

The assessment in terms of land values, rather than an economic evaluation, is relevant as an increase in land values is likely to be the main interest of the present large landowners. The provision of a secure irrigation supply to the area would result in very substantial capital gains for the landowners, which can be realised by subdivision and sale.

The Manuherikia scheme has been operating over a relatively long period, through varying climatic conditions and natural climate oscillations. There has been, and remains, a demand for further irrigation and the extension of irrigation to other land in the Manuherika Valley (and elsewhere in Central Otago). However, scheme upgrades to increase the rate of supply or extend the area of supply are very expensive and only economic if there is a marked intensification in land use. Despite many attempts there has been little extension of irrigation in the area, and where it has occurred it has been in association with other developments, such as the Clyde Dam on the Clutha River.

The projected climatic impacts from the climate change projections are within the variations that would have occurred over the life of the scheme, from the 1920s up to the present. It is unlikely that these impacts would trigger major scheme upgrades. Again, the adaptation would be on-farm.

The operational costs of this scheme are high compared to other schemes that use the area more intensively, at around $120/ha/year. There could be significant additional costs of clearing weeds and sediments from the race network and on farm, and the estimated increases in operational costs would add about $50/ha/year. These costs could have some impact on economic returns. They would be a substantial proportion of the working expenses of dry land sheep and cattle farming in Otago, and could put some pressure on properties that are extensive grazing farms.

Figure 4: Irrigated farmland

FOR MORE INFORMATION

- Report on *Impacts of Climate Change on Rural Water Infrastructure*, prepared by MWH for MAF, June 2010

Appendix C: Irrigation Scheme Case Studies

Southern Valleys Irrigation Scheme

The Southern Valleys Irrigation Scheme (SVIS) is a recently commissioned scheme to supply water to a part of the Wairau Valley to the south of Renwick in Marlborough. It differs from other schemes in that it is managed by the Marlborough District Council and the charges are volume based. The scheme irrigates land that is mostly used for viticulture crops.

The Irrigation Scheme

- A pumped and piped reticulation scheme supplying water to horticultural land
- The scheme supplies 4,500 hectares and was opened in 2005
- Water is sourced from the Wairau River below the confluence with Waihopai River, with water take up to 2,500 L/s
- The intake is located at grid coordinates: 2,571,305E, 5,966,443N

The scheme was constructed to provide irrigation water to viticulture, farming and rural residential properties over an area of approximately 4,500 ha. Water is sourced from the Wairau River immediately below the confluence with the Waihopai River. The water flows from the river into a settlement pond and then via a new water race into Gibsons Creek. The scheme is largely piped, with no storage aside from some on farm storage. The water take also supplies water to a plains stream to recharge stream flows and groundwater.

The main intake pump station is located alongside Gibsons Creek at the end of Hammond Road. A secondary intake pump station is provided at the end of Fareham Lane, supplying water to properties in Fareham Lane and Guernsey Road, at the western end of the scheme. The Hammond Road intake pump station pumps the river water from Gibsons Creek into the piped reticulation network. The scheme includes four booster pump stations to provide a specified rate (per hectare) at a minimum pressure.

Pressurised water is available to each property in the scheme, at a summer application rate of 0.208 l/s/ha (18 m^3/ha/day), or the equivalent of 1.8 mm per day. Water delivery to each property is metered and regulated to control the flow rate.

The Hammond Road intake pump station currently delivers up to 1,000 l/s at 75 m head over the main summer irrigation period using four 280 kW submersible pumps, plus two smaller 75 kW submersible pumps to pump at low flows. The four booster pump stations deliver water through in-line submersible pumps at a range of duties, over the main summer irrigation period. These bypass and do not operate in the winter when system pressurisation is achieved by the two 75 kW pumps at the main intake pump station.

Figure 1: Settlement Pond

SCHEME COMPONENTS

The scheme is primarily a pump and pipe scheme. Details of the scheme components are shown in the following table.

Scheme Component	Description/Details	
Intake structure		
Canal to Gibsons Creek		
Pipework	**Length (m)**	**Diameter (mm) (nominal bore)**
Hammond Road	1,160	900
State Highway 63 (east of Hammond Road Junction)	1,470	160, 110
State Highway 63 (west of Hawkesbury Road Junction)	200	250
State Highway 63 (west of Hammond Road Junction) – Hawkesbury Road - Dog Point Road	4,290	900, 800, 750
Dog Point Road (west of Hawkesbury Road)	1,950	160, 110
Hawkesbury Road (south of Dog Point Road Junction) and Kennedy Road	5,195	300, 250, 200, 160, 100
Brookby Road and Falveys Road	8,075	375, 300, 250, 200, 110, 100
Godfrey Road	1,580	200, 160, 110, 90, 75
New Renwick Road and dirt track	8,425	750, 600, 525, 250, 200, 160, 110, 90
Brancott Road and easement to tank	5,520	375, 160, 110
Wrekin Road	2,230	250, 200, 160, 110
Paynters Road and Bests Road	3,800	450, 375, 250, 160, 110
Ben Morven Road and Paper Road and Corletts Road	7,410	375, 300, 200, 160, 110, 90, 75
Morven Lane	700	110, 75
Fairbourne Drive and Edgehill Lane	1,130	250, 75
Offtakes	**Qty**	**Diameter (mm)**
State Highway 63 (east of Hammond Road Junction)	6	40, 80
State Highway 63 (west of Hawkesbury Road Junction)	2	25, 40
State Highway 63 (west of Hammond Road Junction) – Hawkesbury Road - Dog Point Road	20	25, 40, 50, 80
Dog Point Road (west of Hawkesbury Road)	6	25, 40, 50, 80
Hawkesbury Road (south of Dog Point Road Junction) and Kennedy Road	33	20, 25, 40, 50, 80, 150
Brookby Road and Falveys Road	53	20, 25, 40, 50, 80
Godfrey Road	9	25, 40, 50, 80
New Renwick Road and dirt track	41	25, 40, 50, 80, 100, 150
Brancott Road and easement to tank	16	20, 25, 40, 50, 80, 100
Wrekin Road	18	20, 25, 40, 50, 80, 100
Paynters Road and Bests Road	27	25, 40, 80, 100, 150
Ben Morven Road and Paper Road and Corletts Road	37	25, 40, 50, 80, 150
Morven Lane	11	25
Fairbourne Drive and Edgehill Lane	23	25, 50, 100
Hammond Road Pumpstation Civil Works		
Hammond Road Electrical, Instrumentation and Controls		
Boost Pumpstations Civil Works		
Hawkesbury Road PS 42		
Brookby Road PS 43		
Brancott Road PS 44		
Paynters Road PS 45		
Boost Pumpstations Electrical, Instrumentation and Controls		
Hawkesbury Road PS 42		
Brookby Road PS 43		
Brancott Road PS 44		
Paynters Road PS 45		

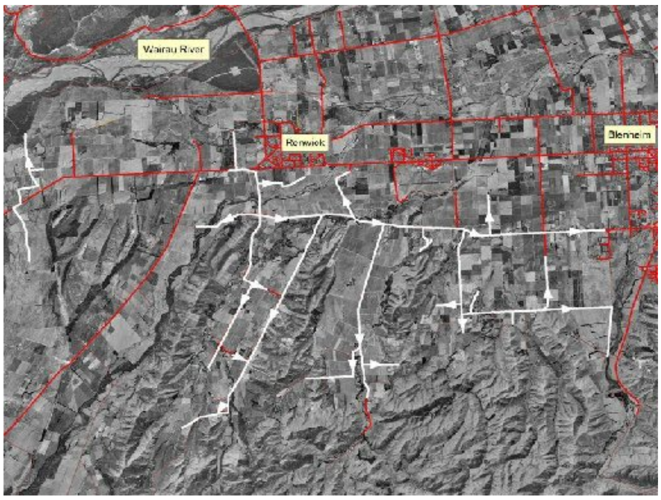


Figure 2: Aerial view of irrigation scheme

The existing scheme operating and maintenance costs supplied by the scheme are:

Scheme Component	Operation/Maintenance Costs
Operation expenses	$120,000 at $26.70/ha/yr
Repairs and maintenance	$160,000 at $35.60/ha/yr
Total annual O&M costs	**$280,000 at $62.30/ha/yr**

Climate Change	Effect
Average rainfall increased but less snow fall and shorter snow melt season	Higher river flows in winter and early spring but possibly lower flows in summer may lead to increased pressure on water resources at times.
Increased risk of drought	Increased frequency and durations of very low stream flows may at times increase pressure on water resources and stream ecology.
Increase in average temperature; Increase in very hot days	Increased summer temperatures in the Wairau River contributing to higher risk of nuisance algae growth and increased variability on DO and pH regimes, placing stream ecology under increased stress. Potentially higher maintenance costs for irrigation scheme infrastructure due to clogging of screens and increased corrosion. May also increase the risk of invasion by other unwanted organisms (but possibly reduced risk associated with didymo).
Increased frequency of heavy rain events	Increased sediment loads in the Wairau and Waihopai River and possibly increased maintenance costs for the scheme. However the extent of sedimentation is affected by the braiding pattern of the river and percentage of water take from the Waihopai River.
Increased summer water deficit for un-irrigated land	Increased water demand for land currently in Scheme

CLIMATE CHANGE EFFECTS

The mean annual rainfall over the entire Wairau River catchment area is projected to increase, with up to 10% more rain expected in winter in the ranges of the upper Wairau catchment. However, there is a projected decrease of 2% from the upper catchment in summer which could result in reduced flows in the river over the summer months. A reduction in snow in the Wairau catchment, of up to 45% at low elevations (1500m) in 2090, could impact on seasonal river flow in spring and early summer when snowmelt traditionally boosts flows. The catchment yield in the Wairau River is dominated by the yield from the upper reaches of the catchment, so any changes will affect the water available for irrigation.

An increase in the frequency of extreme rainfall events may result in increased sediment yields from erosion prone areas in the catchment.

It is projected that the westerly component of wind in Marlborough will increase by 10% within the next 50 years. Wind typically plays an important role in evapo-transpiration, and as a result moisture loss at Southern Valleys is likely to increase.

Temperatures are projected to increase by 0.9°C above current levels by 2040 and 2.0°C by 2090, and the number of very hot days (over 25°C) is projected to increase by 15 to 25 days by 2090. Frosts are expected to decrease in Marlborough, with up to 14 fewer frost days in 2100. There is also a projected increase in the frequency of drought conditions which will require an increase in irrigation to offset the increased evapo-transpiration rates.

The temperature of the river water is projected to increase with rising air temperatures. The middle and lower Wairau in particular will be susceptible to warming in summer due to the width of the braided river that does not receive shading by vegetation. The increase in temperature is likely to contribute to development of algae blooms, weeds and associated water quality effects.

IMPACTS ON INFRASTRUCTURE AND POTENTIAL RESPONSE OPTIONS

Due to the limited storage capacity at Southern Valleys, the demand for irrigation water is highest during periods of dry summer weather when the river flow is low. A projected increase in drought risk, combined with decreased river flows in summer may lead to increased pressure on the water resource.

The increased water temperatures and incidence of algae and weed growth is expected to result in increased clogging of screens, service lines and spray heads and possibly increase pipe corrosion. This will result in the need for increased head pond and pipe sediment cleaning and an increase in the screen capacity.

Scheme Component	Impact	Response Options	Cost Implications	
Intake screens	Weed clogging Sediment erosion	Increase screen capacity of intake by 50%	Additional screen $300,000	
Sediment cleaning	Increased head pond and pipe sediment cleaning	Increased sediment removal	$2/ha/yr	
Pumps	Weed and sediment wear and tear of hydro mechanical equipment	Increased servicing of equipment and reduction of equipment life span (5%)	$11/ha/yr	
Pipes	Minor predicted	Nil	Nil	
On farm irrigation	Damage and clogging to service lines and spray heads	Increased operating costs on farm (10% of operating costs)	$12/ha/yr	

Figure 3: Laying pipes for the irrigation scheme

FEEDBACK FROM THE SYSTEM OPERATORS

The upstream catchment land use at Southern Valleys and the predication of more sediment derived from land use change and flooding will have impacts on operating aspects on the irrigation scheme. A change in river braid patterns will significantly affect sediment loads particularly if greater source water from the Waihopai River is collected, and it may increase river training costs. Supply reliability is predicted to be a concern, and in the future storage may be required.

Water quality and sedimentation are issues for users due to viticulture use. Weed growth is a concern to the system operators. Didymo is of great concern although has not yet been observed at nuisance levels in the Wairau River.

The operating life of pumps and other mechanical equipment is expected to reduce due to wear and tear on equipment, with an increase in annual servicing requirements. Similarly, on farm operation and maintenance costs will increase due to wear and tear of irrigation system infrastructure. The pipe systems are in good condition and the operators do not predict significant changes in the lifespan of the delivery system infrastructure.

The annual operation and maintenance costs are anticipated to increase as a result of climate change to the following levels:

Scheme Component	Operation/Maintenance Costs
Operation expenses	$183,000 at $40.70/ha/yr
Repairs and maintenance	$210,000 at $46.60/ha/yr
Total annual O&M costs	**$393,000 at $87.30/ha/yr**

ECONOMIC AND PRODUCTIVITY ASSESSMENT

The irrigation scheme supplies contracted amounts of water to the landowners, and there is a complex contract agreement covering the operation of the scheme. The price of the water would have been a critical factor for the landowners in agreeing to the scheme. However, the available documentation does not include a cost-benefit analysis of the scheme as an infrastructure project.

As a pump and pipe reticulation scheme, Southern Valleys has constraints on the water supply and upgrading. However, the high water deficits and prolonged droughts in the Wairau Valley under current (or historical) climatic conditions, makes the seasonal increases in potential evapo-transpiration deficit (PED) of projected climate changes relatively small. Increases in daily supply rates would be constrained by pump and pipe network capacities, but marginal increases could be provided by adding to or replacing pumps. The increase in seasonal demands would, in this case, be a rather small percentage of current requirements.

The supply is from a relatively large river, but there is a large area of land that has undergone a rapid intensification in recent years, which could be irrigated from the river. There is also potential hydro-power generation along the lower Wairau River, and the impacts of this on the scheme or other potential irrigation has not been addressed. However, the potential competition and future constraints for a scheme sourcing from a major regional river in a generally water short region will be relatively severe. Climate changes that increase water deficits and reduce summer flows will exacerbate these constraints and any conflicts over water uses.

The structural restrictions of the scheme and likely limitations on any future increases in abstractions from the river, along with the time and cost constraints of scheme upgrades, makes on-farm adaptation the likely response to the projected climate changes. In this case, overall yields may not be greatly depressed given the large deficits of the Wairau Valley and the suitability of grapes to this environment. While grape quantities may be affected, because the available supply from the irrigation scheme becomes a lesser proportion of the potential deficits (in terms of overall soil moisture), quality may not necessarily be affected. The overall economic impact is then difficult to predict. Market requirements and an emphasis on quality to maintain prices may be much more important than marginal impacts from water shortages relative to potential deficits.

The operational costs of this scheme are also likely to increase due to the projected impacts from climate change. This will be due to additional pump wear and tear, weed and sediment removal at the intake and on-farm clogging of the distribution system. An additional screen and screen cleaner may be necessary at the intake, at an estimated cost of $300,000 or $65/ha. The operation and maintenance costs are small on a per hectare basis, at around $60/ha/year. The estimated increases in these costs from weed and sediment effects are also small, at around $20 to $25/ha/year. For grapes, annual working expenses (for a Marlborough model vineyard) are around $10,000/hectare. Taking the irrigation scheme costs as an infrastructure cost, the comparable rates are around $400/ha/year.

Figure 4: Main intake pump station

FOR MORE INFORMATION

- Report on *Impacts of Climate Change on Rural Water Infrastructure*, prepared by MWH for MAF, June 2010

Appendix C: Irrigation Scheme Case Studies

CLIMATE CHANGE IMPACTS ON RURAL WATER INFRASTRUCTURE: CASE STUDY 2

Tablelands Irrigation Scheme

The Tablelands Irrigation Scheme, near Opotiki in the eastern Bay of Plenty, is a small, primarily horticulture based cooperative irrigation scheme. It takes approximately 175 litres per second of water from the Otara River and supplies water to horticultural land on a terrace formation above the river.

The Irrigation Scheme

- A pumped storage and gravity feed scheme supplying water to horticultural land
- The scheme supplies 300 hectares and was opened in 1983
- Water is sourced from the Otara River, with water take at 175 L/s
- The scheme includes a storage reservoir with capacity of 500 m^3
- It serves about 100 shareholders, made up of orchards and lifestyle

The off-farm and on-farm systems were designed as an integrated whole to the design requirement, determined from a water deficit analysis. Water is drawn from an intake in the Otara River through stainless steel intake mesh screens (acting as primary sediment and debris separators) by three submersible pumps located in the wet well. These pump at up to 90 litres per second per pump through a secondary sediment separator known as a hydro-cyclone. The coarse sediment is discharged to collection chambers below the hydro-cyclones and water is then diverted to a break-pressure tank. The break-pressure tank maintains water level control of the supply to the second set of three submersible pumps which lift water up 90 metres via the rising main to the reservoir site on Tablelands. This reservoir has a capacity of 500 cubic metres.

Various valves along the system protect the scheme works against power failure, pump breakdown, and changes in flow. The air pressure cylinder and the three discharge tanks on the rising main protect the system from transient pressure changes in the rising main pipe. The scheme is fully automatic. Gravity distribution from the reservoir site supplies all property turnouts except eleven which require booster pumping. Tertiary sediment mesh filtration is included in each property turnout prior to water passing through the metered control valve.

A surface intake was adopted in preference to a subsurface intake gallery because of the presence of iron and manganese in the river gravels. Removal of these elements would have been very expensive. The stainless steel wire wedge screens act as a debris block and to remove very coarse suspended sediment, of which there is little under normal operating conditions[1].

Figure 1: Otara River and the Intake Structure

[1] Ministry of Works and Development (1984), *Tablelands Irrigation Scheme – Operation and Maintenance Manual*

SCHEME COMPONENTS

The scheme is primarily a pump and pipe scheme. Details of the scheme components are shown in the following table.

Scheme Component	Description/Details
Intake	Stainless steel intake mesh screens (acting as the primary sediment and debris separators). The size of the slot openings is 0.5 mm and each of the 10 screens may be lifted individually.
Wet well/low-head pumps	Three submersible pumps (pump up to 110 litres per second per pump).
Sediment removal (hydro-cyclones)	Secondary sediment separator. The function of the hydro-cyclones is to remove sand sized particles.
Break-pressure tank	This maintains the water level control of the supply to the high-head pumps.
High-head pumps	Three submersible pumps lift water via the rising main to the reservoir site. Each high-head pump forms a set with a corresponding low-head pump.
Rising main	Various valves along the system protect the scheme against power failure, pump breakdown, and changes in flow. An air pressure cylinder and three discharge tanks protect the system from transient pressure changes in the rising main pipe. The rising main is approximately 900 metres long. All rising main pipes are 300 mm nominal diameter spiral welded steel.
Pressure vessel	The main protection against water hammer in the rising main is provided by the pressure vessel. This is a hydro-pneumatic cylinder which injects water under pressure into the rising main when the velocity of the water column slows down.
Discharge tanks	Along the flatter section of the rising main, three discharge tanks provide protection against water hammer.
Reservoir	This is situated at the highest point in the scheme and enables all but four properties to be serviced by gravity reticulation. The volume is 500 cubic metres and at full demand the reservoir would empty in approximately one hour.
Booster pumps	Eleven turnouts are at the same elevation as the reservoir and therefore require booster pumping to provide the required head at the property turnouts. There is one additional booster pump that is utilised for pressure control during periods of high demand.
Turnouts	From the reservoir, water is piped to the individual farms through the turnout structures and then via the on-farm reticulation to the orchards.
Pipework and fittings	Exposed pipework at the intake and reservoir - hot-dip galvanised mild steel pipe Rising main - spiral-weld pipe with a concrete-lined interior and coal-tar enamel exterior coating Reticulation - asbestos cement for diameters 375 mm down to 100 mm and uPVC for smaller diameters Reducers/bends - cast iron fittings
Air valves and scours	Three different types of air valves are incorporated into the pipeline (automatic, kinetic, and double purpose). These valves are located on high points and/or approximately every 500 metres. At major low points in the pipework, scours are required to clean and/or drain the lines. Energy dissipaters were constructed at these scours to reduce water velocities at the outlet.

Figure 2: Storage Reservoir

The existing scheme operating and maintenance costs supplied by the scheme are:

Scheme Component	Operation/Maintenance Costs
Operation expenses	\$39,000 at \$130/ha/yr
Repairs and maintenance	\$20,000 at \$67/ha/yr
Total annual O&M costs	**\$59,000 at \$197/ha/yr**

CLIMATE CHANGE EFFECTS

The mean annual rainfall over the Otara catchment area is projected to increase slightly, although with seasonal variations a decrease in rainfall is projected in spring. This may lead to increased pressure on water resources at times. An increase in the frequency of extreme rainfall events may result in increased sediment yields and erosion.

Temperatures are projected to increase by 0.9°C above current levels by 2040 and 2.1°C by 2090, and the number of very hot days (over 25°C) is projected to increase by 25 to 35 days by 2090. There is also a projected increase in the frequency of drought conditions, which will require an increase in irrigation to offset the increased evapo-transpiration rates.

The temperature of the river water is projected to increase with rising air temperatures, although the extent of warming is subject to a number of factors including shading of the riverbed by vegetation. The increase in temperature is likely to contribute to development of nuisance algae blooms and weeds.

Projected sea level rise will increase the pressure of salt water intrusion under the plains close to the coast, and may cause problems with groundwater rise and additional drainage requirements.

Climate Change	Effect
Average rainfall increases in summer and autumn but decreases in winter and spring	Annual rainfall not greatly different from present but seasonal variations may lead to increased pressure on water resources at times, particularly in spring.
Increased risk of drought	Increased frequency and durations of very low river flows may at times increase pressure on water resources. Minimum/environmental flow could be reached more often and abstraction for the scheme reduced or halted for periods of time.
Increase in average temperature; Increase in very hot days	Increased temperatures in river water contributing to higher risk of nuisance algae development and increased variability on DO and pH regimes, placing stream ecology under increased stress. Potentially higher maintenance costs for irrigation scheme infrastructure due to increased corrosion.
Increased frequency of heavy rain events	Increased sediment yields and erosion in the Otara catchment, potentially leading to high maintenance costs for the irrigation scheme infrastructure.
Increased summer water deficit for un-irrigated land	Increased water demand for land currently in the Scheme.

IMPACTS ON INFRASTRUCTURE AND POTENTIAL RESPONSE OPTIONS

The projected increases in average and drought (1:20 year return period) deficits are large compared to existing potential evapo-transpiration deficits (PEDs). However as the scheme is run of river, extending the period of take may be achievable by consent variation, given a relatively low level of demand in the area and projected increases in summer flows.

In terms of daily rates, there may be some potential for increasing supply rates by changing scheme components. Adding stages to existing pumps, or replacing the pumps could increase the pumping rate. However there may be incompatibilities with other components, such as the sediment removing equipment. Power costs would also increase, with head losses being relatively high as more water is pumped up the existing pipes. The supply to the properties from the control reservoir at the top of the scheme is by gravity flow, thus higher flow rates would result in lower on-farm pressures, and the turnout control equipment would have to be adjusted or replaced. Alternatively, booster pumps could be added into the reticulation network.

Upgrading the scheme infrastructure to allow a significantly higher watering rate is likely to be complicated and involve much of the scheme equipment. For a substantial increase, the whole pipe network would become a constraint. Determining the cost of such upgrading would require considerable effort in terms of engineering re-design and cost estimating.

The upgrade, in terms of options, approach, costs and financing, would have to be agreed to by the scheme owners. This would take time, depending on the type of corporate or collective organisation used to operate and manage the scheme. There would then be the time and cost of obtaining a consent variation.

Scheme Component	Impact	Response Options	Cost Implications	
Intake screens	Weed clogging Sediment erosion	Increase screen capacity of intake by 50% and install mechanical screen cleaner	Additional screen $100,000 Screen Cleaner $170,000	
Pumps	Wear and tear of hydro mechanical equipment	Increase servicing of equipment and reduce equipment life span	$40/ha/yr	
Pipes	Negligible predicted as pipelines are asbestos	Nil	Nil	
On farm irrigation	Damage and clogging to service lines and spray heads	Increased operating and maintenance costs on farm	$90/ha/yr	

Figure 3: Headworks (sediment removal, pumps, break pressure tanks)

FEEDBACK FROM THE SYSTEM OPERATORS

Tablelands Irrigation Scheme is experiencing a land use move from horticulture to lifestyle. This is an issue for the supply water quality.

Upstream catchment land use and the predication of more sediment (as a result of land use changes and flooding) will impact on the operation of the scheme.

Weed growth is a primary concern to the system operators as they are starting to experience an increase in weed clearing requirements. It is predicted that new or increased capacity intake screens and a mechanical weed cleaner will be required. Didymo is of great concern although has not been recorded in the Otara River yet.

The operating life of pumps and other mechanical equipment is expected to reduce due to wear and tear on equipment, with an increase in annual servicing requirements. Similarly, on farm operation and maintenance costs will increase due to wear and tear of irrigation system infrastructure. The pipe systems are in good condition and the operators do not predict significant changes in the lifespan of the delivery system infrastructure.

The annual operation and maintenance costs are anticipated to increase as a result of climate change to the following levels:

Scheme Component	Operation/Maintenance Costs
Operating expenses	$62,000 at $208/ha/yr
Maintenance expenses	$32,000 at $107/ha/yr
Administration	$20,000 at $67/ha/yr
Total annual O&M costs	**$114,000 at $382/ha/yr**

ECONOMIC AND PRODUCTIVITY ASSESSMENT

The economic evaluation undertaken for this scheme prior to construction assumed all the potential irrigable land would be used for intensive horticulture (kiwifruit, passionfruit, tamarillos and citrus, with mostly kiwifruit). The scheme covered a relatively distinct terrace area, of about 300 hectares, which was mostly in horticultural use, and it was assumed that the remaining terrace land would convert to horticulture whether the irrigation scheme proceeded or not.

The benefits of irrigation were increased yields, or greater productivity from the existing (or future) land use. A relatively small percentage increase in fruit yield was used, of around 10%. At the produce prices used in the evaluation, this was sufficient to make the scheme highly economic.

The most likely response to climate change would be on-farm adaptation, at least initially. The benefits of the scheme are likely to be lost over time, as the water requirements for the crops increases, or yields decline because of lower soil moisture levels. The simplest adaptation is to water less of the crop area on the property, although a lower yield over the whole crop area may result in the best overall yield for the water available. A further adaptation would be to change the crop on non-irrigated areas, to one more tolerant of lower soil moisture levels and prolonged dry periods. Given the short life span of many horticultural crops and the re-planting with different varieties that occurs in the industry, this adaptation would fit easily into industry practices.

The economic interests of the property owners may give rise to on-farm and land use adaptations, with lower overall yields, unless there was strong economic pressure to maintain or increase yields. This pressure on yields would have to be widespread among the scheme landowners to bring about a scheme upgrade, with the costs and difficulties of doing this and the agreements required. A national interest in maintaining yields and hence export produce, may not align with the economic interests of the property owners, and the difficulties they face in upgrading the irrigation scheme.

The scheme was constructed because of a mutual interest by nearly all the property owners at the time in horticultural development, and increasing the yield of high value crops — at that time mostly kiwifruit. Substantial financial and scheme operational (design, construction and operation) support from central government was also important in aligning national and private interests in irrigation.

The operational costs of the scheme are likely to increase due to additional weed growth and sediment supply. This would affect pump wear and tear, weed and sediment removal at the intake and on-farm clogging of the distribution system. An additional screen and screen cleaner may be necessary at the intake, and this has been estimated at $270,000. The increase in operation and maintenance costs due to these effects has been estimated, with annual costs rising from about $200/hectare to around $380/hectare. This is close to a 100% increase, however these costs are small compared to on-farm servicing and production costs. For a kiwifruit orchard, annual working expenses (for a model orchard) are around $25,000/hectare. The irrigation scheme costs can be seen as another infrastructure cost, like rates for public infrastructure, and rates and insurance alone can be over $1000/ha/year.

Figure 4: Otara River intake

FOR MORE INFORMATION

- Report on *Impacts of Climate Change on Rural Water Infrastructure*, prepared by MWH for MAF, June 2010

Appendix D: Rural Water Supply Scheme Case Study

CLIMATE CHANGE IMPACTS ON RURAL WATER INFRASTRUCTURE: CASE STUDY 6

Rural Stock Water Supply Schemes

Rural Stock Water Supply Schemes

- Cold Creek scheme – an on-demand gravity scheme serving an area of 7,600 hectares
- Hunterville scheme – a constant flow pumped/gravity scheme serving an area of 10,000 hectares
- Wainuioru scheme – a constant flow pumped scheme serving an area of 7,000 hectares
- Redwoods scheme – a constant flow pumped scheme serving an area of 2,500 hectares
- Malvern scheme – a constant flow pumped/gravity scheme serving an area of 6,300 hectares
- Rocklands scheme – a constant flow pumped/gravity scheme serving an area of 1,500 hectares
- Homestead scheme – a constant flow pumped/gravity scheme serving an area of 2,200 hectares

There are a large number of piped rural water supply schemes throughout New Zealand. They vary in size and water source, and hence off-farm infrastructure, but they all provide the same service of a reticulated water supply to troughs on farms for stock water. Seven schemes make up this case study to provide a representative set, in terms of regional location, size and water source.

The rural water supply schemes provide stock water to large areas of farm land. The water demand for these schemes is much smaller than for irrigation schemes, and very much smaller on a per hectare basis. Rural water supply demand is typically around 100L/ha/day for sheep grazing, to up 500L/ha/day for dairy farming operations. This compares to typically 50,000L/ha/day for irrigation water demand, at least two orders of magnitude greater than rural water supply systems.

The case study schemes cover a range of climatic regions across New Zealand, with water takes varying from 4040m^3/day (46.8 L/s) for Cold Creek RWS, down to 426m^3/day (5 L/s) for Rocklands RWS . The schemes areas range from 1500 hectares for Rocklands to 10,000 hectares for Hunterville RWS.

This case study has sought to identify likely impacts of climate change on the water sources and intake structures, particularly in terms of operation and maintenance. Because the water take volumes and flow rates are much less than for irrigation schemes, the scale of the infrastructure is much less and potential impacts are likely to be correspondingly less than the irrigation scheme scenarios. Energy assessments have been undertaken since most rural water supply scheme involve pumping at significant heads through long pipeline systems.

Figure 1: Rocklands RWS water treatment plant

SCHEME COMPONENTS

The schemes that comprise this case study can be classified into three different scheme types:

- On-demand, gravity schemes with surface water source;
- Constant flow pumped and/or gravity scheme with surface water source; and
- Constant flow pumped scheme, with water sourced from groundwater (either inland or coastal).

On-demand gravity type scheme

Cold Creek RWS scheme is an example of an on-demand gravity scheme from a surface water source. These schemes typically have a main storage reservoir which provides the head for the farms being served from the scheme. With the exception of any treatment process pumping, the scheme runs by gravity with flow metering at each farm turn-out. Pressure reducing valves are typically used for pressure control. The main scheme components for an on-demand gravity type scheme are:

- Surface water intake: gallery or side entry weir with screens
- Treatment process, typically filtration and chlorination
- Large storage
- Pipe networks
- Pressure reducing valves
- Farm turn-out meters and backflow preventers.

On-demand schemes are suited to farming operations where there are existing on-farm systems. The major benefit is that farmers can utilise their existing on-farm systems, negating the need for pumps.

Constant Flow Pumped and /or Gravity Systems (Surface Water Source)

Constant flow rural water supply schemes are the most common in New Zealand. Typically, these schemes involve either pumping from a surface water source to a main scheme reservoir or involve capturing a water source above the scheme area and providing gravity flow to a main scheme reservoir. The water is delivered by gravity to the individual farm properties on a 24 hour basis through a restrictor or a meter to on-farm storages. The farms are then reticulated from these storages with pipe networks sized for the peak demands. The on-farm storages provide the storage buffer for the peak demand.

Hunterville, Malvern, Rocklands and Homestead RWS schemes are all examples of constant flow pumped and/or gravity systems. The main scheme components comprise:

- Intakes
- Pumps
- Treatment processes
- Rising mains
- Main reservoirs
- Gravity reticulation
- Farm turn-outs (restrictors or meters)
- On farm storage
- On farm reticulation.

Constant Flow Pumped Schemes with Groundwater Source

Constant flow pumped schemes, with water sourced from groundwater, are based on the same principle as surface water constant flow schemes, the main difference being the source for the schemes. The groundwater source provides different potential impacts from climate change in terms of source quantity and source quality as well as availability.

Two schemes were selected to assess the impacts of a groundwater sourced rural water supply scheme: Wainuioru rural water supply in the Wairarapa which is an inland scheme; and Redwoods Valley scheme near Richmond in the Nelson region which is a coastal scheme. The main difference between the two is that the Redwoods Valley scheme is situated close to the coast and is likely to be impacted by sea level rise and salt water intrusion.

Figure 2: Wainuioru RWS staging site pumpstation

CLIMATE CHANGE EFFECTS

An assessment of the meteorological and hydrological effects projected from climate change was undertaken for each of the rural water supply schemes. Average annual rainfall is projected to remain at similar levels, with some seasonal variations. An increase in heavy rainfall events is expected at all the schemes.

Temperatures are projected to increase by an average of 0.9°C above current levels by 2040 and 2.0°C by 2090, coupled by an increase in the number of very hot days (over 25°C). The frequency of drought events is also projected to increase.

The impacts on the rural water supply schemes of the projected effects of climate changes were similar for all regions, with some exceptions.

In the Nelson and Southland regions, annual rainfall is projected to increase, and as such the pressure on the surface water resource is not expected to increase for the Redwoods and Homestead RWS schemes. At the Homestead scheme, outbreaks of didymo are projected to increase requiring more maintenance at the intakes although the increase in the number of very hot days is not expected to significantly impact on the demand and need for upgrading reticulation.

Climate Change	Effect
Average rainfall increases in all cases with some variations in the seasons	Annual rainfall higher than at present but seasonal variations may lead to increased pressure on water resources at times.
Increased risk of drought	Increased frequency and durations of very low river flows may at times increase pressure on water resources. Minimum/environmental flow could be reached more often and abstraction for schemes reduced or halted for periods of time. However due to the relatively small water take in relation to the river flow, the risk of reduced access to water is probably low.
Increase in average temperature	Increased temperature of river water contributing to higher risk of nuisance algae development and increased variability on DO and pH regimes, placing stream ecology under increased stress. Potentially higher maintenance costs for rural supply scheme infrastructure due to clogging and increased corrosion.
Increased frequency of heavy rain events	Increased sediment yields and erosion in each of the river catchments, potentially leading to high maintenance costs for rural water supply scheme intake infrastructure. Increases in heavy rainfall will also result in effects on pipeline stability.
Sea level rise	Bores near the coast will have an increased risk of saltwater intrusion.
Decrease in groundwater levels	Increase in pumping head.
Increase in very hot days	Increase in peak demand for stock watering.

IMPACTS ON INFRASTRUCTURE AND POTENTIAL RESPONSE OPTIONS

Given the priority accorded domestic and stock water, future restrictions on supply are unlikely for the projected climatic changes of the study. The impacts will be on scheme operations and the service level. This is due to increased stock water requirements with increasing temperatures and the effect on peak demand of higher maximum temperatures and the number of very hot days during summer months.

Schemes with direct river intakes and screens will be affected in the same way as irrigation schemes with direct intakes. Given the low water takes of rural water supply schemes many intakes are indirect, through infiltration galleries or bores beside the river channel. These intakes and groundwater supplies will be little affected, if at all, by changes in river water flows or quality.

The schemes are generally flow restricted, with a continuous and constant flow to each property. The peak demand on farm is then managed through on-farm storage reservoirs. If peak stock water demand increases, then both on-farm and off-farm infrastructure would have to be upgraded. Most of the schemes have a pumped supply to storage reservoirs, and the distribution network is fully piped. Thus additional flow could be delivered by adding extra pump and reservoir storage capacity. This additional capacity could be installed as add-ons, and would have a small area footprint within the rural landscape.

The importance of stock water for animal health and productivity makes scheme upgrades a likely response following episodes of high stock stress due to prolonged droughts or a period of very hot days. Scheme upgrades would face organizational issues, including landowner agreement about upgrade options and financing. Consent variations may also be required, depending on the type of upgrade.

Scheme Component	Impact	Response Options	
Bores close to the coast	Potential saltwater intrusion	May require additional bore source due to decline in yield or require shifting bores due to saltwater intrusion.	
Bores	Lower groundwater levels and reduced yields	May require additional bore sources due to decline in yield from reduced recharge.	
Intakes	Weed clogging and sedimentation	Increase in screen cleaning and intake maitenance. May require increase in intake capacity due to increased demand.	
Pumps	Change in duty due to increased flows and increase in heads	Increase in demand will require upgrade of pumps with additional flow capacity.	
Treatment processes	Increased usage with more wear and tear	Will most likely need to be upgraded in line with additional flow requirements.	
Rising main	Additional sedimentation and reduced level of service	Possible hillside stability issues requiring more maintenance, particularly in Nelson area.	
Main reservoir size	Stability issues with sub surface conditions. Overall water usage increased impacting level of service of main reservoir.	Increase storage capacity to maintain level of service.	
Gravity reticulation	Gravity reticulation – reduced level of service	Network capacities and pipeline sizing will need to be reviewed against increased demands.	
On farm storage	Reduced level of service	Increase storage capacity.	
On farm reticulation	Reduced level of service	Improve on farm reticulation to accommodate increase in peak demands.	

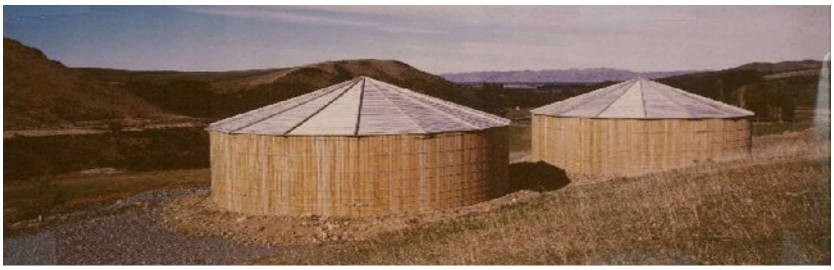


Figure 3: Timber tanks

ECONOMIC AND PRODUCTIVITY ASSESSMENT

Economic evaluations carried out at the time of scheme approval have been obtained for three of the case study schemes (Cold Creek, Hunterville and Wainuioru). These evaluations were based on benefits from increases in stock carrying capacity, improved stock performance and hence productivity, and saved costs of pre-existing supplies, mostly on-farm dams or springs and creeks. The estimated increases in stock numbers were around 10 to 15% of farm carrying capacity, while improved stock performance (over all farm stock) could be 50 to 100% of the benefits from greater stock numbers.

The increase in stock numbers was because of better grazing management from more watering points and subdivision fencing. The more accessible and better quality water of the scheme supply improved stock health and performance. For the projected climate changes, the grazing management benefits of the schemes, which included on-farm reticulation and subdivision fencing, would probably not be much affected. The installed infrastructure remains in place, and continues to provide this benefit, albeit with higher stock watering demands.

Climate changes may affect stock carrying capacity for reasons other than water supply (being the amount of water available to stock and the number or proximity of watering places). The more severe the extremes of temperature and dryness, the greater the pressure on stock in terms of both feed and water. A sufficient supply of water is critical to stock health and the maintenance of sufficient stock condition to minimise longer term effects.

The additional stock performance and stock numbers because of the schemes could be affected by the impacts of the projected climate changes of the study. This would reduce farm production and hence economic returns. However, the overall impacts on farm economics is likely to be relatively marginal, with other impacts and market changes in produce price and farm costs being more significant.

The likely responses would be a combination of scheme upgrades and reduced stock numbers, where the supply constraints of the existing schemes were having significant impacts.

The scheme infrastructure, both off and on-farm, could be significantly impacted by an increase in the intensity of storm events or the frequency of high rainfall events. The infrastructure of these rural water supply schemes is vulnerable to erosion and landslide damage. Many of the piped distribution networks go through steep and erosion prone land, while storage reservoirs and pump stations may also be at relatively high risk from these hazards. Operation and maintenance costs could be affected by these hazards. These additional costs are not predictable.

The rural water supply schemes will be less affected by impacts on river flows and quality than irrigation schemes, given their low per hectare demands for water and generally less exposed and at-risk intake systems. While the water demand of stock is related to plant watering requirements (of dryness and water deficits), it is not the same and the effects on stock of water restrictions have not been well researched.

Having sufficient water for stock through dry periods is critical for stock health and condition, while the relatively low flow rates and piped reticulation of the schemes makes add-on upgrading more practical for these schemes. These upgrades would increase operational costs, such as power charges, as well as the capital investment required. There could be some increase in operational costs at intakes, although probably relatively small. Costs could also increase for other reasons, such as from more erosion and slip damage.

The rural water supply schemes provide a critical service to farms, and like irrigation schemes, they will provide significant advantages to the landowners within the scheme areas, in terms of water security and management flexibility.

Figure 4: Hunterville RWS pipeline installation

FOR MORE INFORMATION

- Report on *Impacts of Climate Change on Rural Water Infrastructure*, prepared by MWH for MAF, June 2010

Appendix E: Detailed Climatic and Ecological Analyses

The following climatic analyses make use of the New Zealand downscaled projections from the 'Fourth Assessment Report' (MfE 2008). These projections are for changes over time periods of 50 and 100 years from the baseline climate (which is 1990). Therefore projected changes are shown for 2040 and 2090.

Information was sourced from a number of additional reports. This includes 'The New Zealand Climate: Present and Future' (Mullan et al 2001), which provides projections on the number of days with temperatures exceeding 25°C and number of frost days (or days where temperature is less than 0 °C) for 2050 and 2100. The report on 'Changes in Drought Risk with Climate Change' (Mullan et al 2005) uses dates of 2030 and 2080 for drought projections.

E.1 Irrigation Scheme Case Study Analyses

E.1.1 General

There are a number of projected climatic changes that are common to each of the irrigation schemes, as outlined below.

E.1.1.1 Wind Speed and Direction

Changes in wind speed have been modelled for climate change projections. Future scenarios show a strong bias towards increasing westerly flow, particularly in autumn and winter (Pearce et al 2005).

Results suggest that the mean westerly component will increase by about 10% of its current values within the next 50 years (MfE 2008). There is still substantial uncertainty about projected future wind changes.

E.1.1.2 Sediment or Erosion Issues

The projected increase in the frequency and magnitude of heavy rainfall events are likely to lead to increased sediment yields from erosion prone areas within each scheme catchment.

E.1.2 Kerikeri Irrigation Scheme

E.1.2.1 Rainfall

Seasonal and annual rainfall projections are provided (MfE 2008) for two locations within Northland - Kaitaia and Whangarei. Table 0-1 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090.

Table 0-1: Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040		2090	
	Kaitaia	Whangarei	Kaitaia	Whangarei
Summer	1	1	-1	0
Autumn	0	1	-3	1
Winter	-5	-9	-8	-12
Spring	-6	-9	-11	-16
ANNUAL	-3	-4	-6	-7

The Kerikeri area is closer to Kaitaia but could be argued to have closer rainfall characteristics to Whangarei given the easterly location and hill backdrop.

The projected changes (Table 0-1) have been averaged to provide an indication of the potential magnitude of changes to rainfall in the Kerikeri scheme area. Table 0-2 details monthly and annual rainfall totals for the raingauge recorder at Taus Falls, which is representative of the catchment area above the storage dams. The current and projected 2040 and 2090 totals are shown.

Table 0-2 : Projected Rainfall Totals at Taus Falls Raingauge

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Current	140	153	181	170	168	239	241	236	188	173	152	142	2182
2040	142	155	182	170	169	222	224	219	174	160	141	143	2101
2090	140	153	180	168	166	215	217	212	162	149	131	141	2034

Seasonal rainfall totals and projected changes for the Taus Falls raingauge are detailed in Table 0-3. Winter rainfall is expected to decrease by 50mm in 2040 and by 72mm in 2090.

Table 0-3: Projected Seasonal Changes in Rainfall Totals at Taus Falls Raingauge

	Current	2040	*Difference*	2090	*Difference*
Summer	435	440	*4*	433	*-2*
Autumn	519	522	*3*	514	*-5*
Winter	715	665	*-50*	644	*-72*
Spring	512	474	*-38*	443	*-69*
ANNUAL	2182	2101	*-82*	2034	*-148*

The two storage dams harvest high flows during the winter (and possibly spring) months.

The projected reduction in rainfall during the winter (and spring) months means less runoff will be available to be captured for storage and subsequently released for irrigation purposes in summer and autumn.

E.1.2.2 Heavy Rainfall Events

A warmer atmosphere can hold more moisture – about 8% for every 1°C increase in temperature (MfE 2008). The Northland region has the highest projected temperature increases in New Zealand, so therefore also the highest projected percentage increase in heavy rainfall in the country.

The projected percentage changes in temperature for Northland (Table 0-4) have been used to derive the projected percentage increase in heavy rainfall, as detailed in Table 4 for 2040 and 2090.

Table 0-4 : Percentage Increase in Heavy Rainfall in Northland

	2040					2090				
ARI (years)	Duration (hours)					Duration (hours)				
	1	**2**	**6**	**12**	**24**	**1**	**2**	**6**	**12**	**24**
10	6.7	6.5	6.1	5.9	5.7	15.5	15.1	14.3	13.7	13.2
20	6.9	6.8	6.7	6.6	6.5	16.2	16	15.5	15.3	15.1
50	7.2	7.2	7.2	7.2	7.2	16.8	16.8	16.8	16.8	16.8
100	7.2	7.2	7.2	7.2	7.2	16.8	16.8	16.8	16.8	16.8

The projected increases have been applied to design heavy rainfall totals that have been derived for the Maungaparerua at Tyrees Ford raingauge (MWH 2009) which is located in the Kerikeri area, approximately 3km north of Lake Waingaro and 6km south of Lake Manuwai.

Table 0-5 details the current design heavy rainfall totals for durations between 1 and 24 hours over the 10, 20, 50 and 100-year average recurrence intervals (ARI). The results show that a current one in 50-year ARI extreme rainfall event (e.g. 272mm over 24 hours) is projected to occur one in every 30-years by 2040, and one in 20-years by 2090. The frequency of a current one in 20-year ARI heavy rainfall event will double to one in 10-years by 2090.

Table 0-5 : Heavy Rainfall Design Events (mm) - Maungaparerua at Tyrees Ford Rainfall

	Duration (hours)				
ARI (years)	**1**	**2**	**6**	**12**	**24**
Current					
10	41	62	110	148	206
20	46	70	123	165	235
50	52	81	141	187	272
100	57	89	154	204	300
2040					
10	44	66	117	157	218
20	49	75	131	176	250
50	56	87	151	200	292
100	61	95	165	219	322
2090					
10	47	71	126	168	233
20	53	81	142	190	270
50	61	95	165	218	318
100	67	104	180	238	350

Increased rainfall intensity has obvious implications for increased flooding. Design parameters of the two storage lakes, such as spillway sizing and gate structures, may need to be re-evaluated to cope with more frequent large flood events.

More heavy rainfall events could conceivably help counteract the expected decrease in average rainfall over winter by providing more runoff to put into storage. However, there is no guidance as to when increased heavy rainfall events might occur, and associated increases in turbidity and sediment content of stream flows during flood events may make diversion for storage unpractical.

E.1.2.3 Air Temperature

Projections of changes in mean seasonal and annual temperature for Northland are detailed in Table 0-36 (MfE 2008). Northland is projected to experience the greatest increases when compared to the rest of the country.

Table 0-6 : Average Projected Change in Mean Annual and Seasonal Temperature (°C) – Lower and Upper Limits in Brackets

Season	2040	2090
Summer	1.1 *(0.3, 2.7)*	2.3 *(0.8, 6.6)*
Autumn	1.0 *(0.2, 2.9)*	2.1 *(0.6, 6.0)*
Winter	0.9 *(0.1, 2.4)*	2.0 *(0.5, 5.5)*
Spring	0.8 *(0.1, 2.2)*	1.9 *(0.4, 5.5)*
ANNUAL	0.9 *(0.2, 2.6)*	2.1 *(0.6, 5.9)*

In comparison to the current Northland climate it is projected that by 2040 there will 10 to 20 more days where the temperature will exceed 25° C (MfE 2008, Mullan et al 2001). By 2090 there is projected to be 15 to 70 days more above 25° C. The number of days above 25^{o}C in Northland typically doubles by 2100 (Mullan et al 2001).

Frosts (or days where temperature is less than 0° C) are already very rare in Kerikeri – averaging less than 0.3 days per year (Mullan et al 2001). Projected changes to days with frost show a reduction of 1 day in both 2050 and 2100.

E.1.2.4 Drought

Changes in drought risk are generally caused by extended periods of no, or very limited, rainfall.

Mullan et al (2005) adopt the potential evapo-transpiration deficit (PED) as a measure of drought or water deficit. This measurement incorporates the climatic factors of rainfall, temperature and wind.

PED is calculated for unirrigated land and is measured in millimetres. It can be thought of as the amount (depth) of water needed to supply a crop, in addition to actual rainfall. A PED of 200mm over a growing season could be overcome by applying 200mm of irrigation water at appropriate times.

PED for an average year in the Kerikeri area is projected to increase by between 90 to 120mm by 2080. A PED with a 20-year ARI (or return period) is used to describe extreme drought conditions.

Table 0-37 details the PED with a 1 in 20-year ARI for Kerikeri as interpreted from Mullan et al (2005). This 20-year ARI PED value is 350mm for Kerikeri. Projections of the change to this in 2030 and 2080 are shown in the table for two downscaled global climate models: “low-medium” and, “medium-high” (Mullan et al 2005).

Table 0-7 : Current one in 20-Year ARI PED at Kerikeri and Projected Changes

	PED (mm)		Average ARI for current 20-year drought (years)	
Current	***2030 Low-Medium***	***2030 Low-High***	***2030 Low-Medium***	***2030 Low-High***
350mm	450mm	450mm	15-year	10-year
Current	***2080 Low-Medium***	***2080 Low-High***	***2080 Low-Medium***	***2080 Low-High***
350mm	450mm	550mm	10-year	5-year

Projections for 2030 show the current 20-year ARI PED of 350mm to increase to 400-450mm based on the two models. A PED of 350mm increases in frequency of occurrence from a 1 in 20-year ARI to a 1 in 10 to 1 in 15-year ARI event. By 2080, a 20-year ARI PED is estimated to be 450 to 500mm. The 1 in 20-year ARI PED (350mm) increases in frequency to a 1 in 5 to a 1 in10-year ARI.

The PED results presented are for unirrigated pasture. They therefore give an indication that within the Kerikeri scheme an increase in irrigation will be necessary to offset the increases in PED.

Projected increases in the frequency of repeat drought events have been calculated (EcoClimate 2008). A PED drought threshold of 200mm has been used (equal to approximately a 2 to 5-year ARI in Kerikeri) and the results presented in Table 0-8. The frequency of repeat droughts of this magnitude in Northland is currently 31%. The frequency is projected to increase to around 40% by 2030, and to between 42 and 52% by 2080.

Table 0-8 : Chance of Repeat Annual Occurrence of PED of 200mm in Northland

Current	2030 Low-Medium	2030 Medium-High	2080 Low-Medium	2080 Medium-High
31%	39%	41%	42%	52%

E.1.2.5 Groundwater Levels and Saltwater Intrusion

Water balance modelling of the Kerikeri groundwater resource (SKM 2008) estimates that 15 to 20% of the mean annual rainfall becomes groundwater recharge. A reduction in mean annual rainfall (as detailed in Section E.1.2.1) will mean a reduced rainfall recharge component and possibly lower groundwater levels.

Projected sea level rise and reduced groundwater levels could result in seawater intrusion to the aquifer near the coast. The Kerikeri Irrigation Scheme is sourced from surface water so would not be affected by such a scenario.

E.1.2.6 Water Temperatures

At Kerikeri it is projected that the average air temperature will increase 0.9°C above current levels by 2040 and 2.1°C by 2090. An increase in average water temperature of streams and rivers is also projected, but the magnitude of that change is subject to a number of factors including:

- Stream base flows and water depths: projected lower base stream flows and shallower water depths will contribute to increased water heating in summer.

- Intactness of riparian vegetation: streams from which riparian vegetation has been cleared and shading over waterways reduced are far more susceptible to summer heating than those which have retained a closed canopy. Restoration of riparian vegetation, already widely promoted by some Regional Councils, has the potential to offset temperature increases in small to medium sized waterways.

Average water temperatures in the Lake Manuwai and Lake Waingaro reservoirs, which have maximum depths of 28 and 32.4 metres respectively, are expected to increase approximately in line with average air temperatures.

E.1.2.7 Water Quality and Aquatic Ecology

The location of the Kerikeri Irrigation Scheme in the upper catchment has helped to reduce some of the risks associated with warmer temperatures, lower base flows in the streams and more extreme heavy rainfall events. The scheme harvests water at times of high rainfall and does not necessarily need to reduce stream flows in dry conditions, thus minimising pressure on downstream waterways. Nevertheless, projected lower stream flows may lead to a renewed focus on a sustainable residual flow regime for the Waipapa and Waiwhakangarongaro Streams, with possible consequences for quantities of water available for irrigation.

Increased temperatures in Lakes Manuwai and Waingaro, as well as increased sediment and nutrient inputs during heavy rainfall events and increased atmospheric carbon dioxide levels, may increase the likelihood of nuisance algae blooms, weeds, pest fish or other unwanted organisms in the future, with possible consequences for the quality of irrigation water distributed through the Scheme. Serious weed infestations or algae blooms could lead to increasingly variable pH and dissolved oxygen regimes, with possible consequence for irrigation scheme infrastructure (clogging of screens, pipe corrosion, etc). Better control of sediment and nutrient inputs to the lakes might be achieved by more extensive riparian or catchment planting in the upstream catchment.

E.1.3 Tablelands Irrigation Scheme

E.1.3.1 Rainfall

Annual rainfall ranges from around 1400mm at Opotiki, to 1600mm where the Otara River exits the foothills, up to approximately 2500mm at the top of the Otara catchment. Seasonal and annual rainfall projections are provided for the Otara catchment. Table 0-9 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090.

Table 0-9 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040		2090	
	Otara	Tauranga	Otara	Tauranga
Summer	2.5	2	-1	2
Autumn	3	3	3	2
Winter	1	-4	5	-3
Spring	-5	-5	-6	-9
ANNUAL	2	-1	2	-2

The projected changes to mean annual rainfall show an overall increase over the Otara catchment area above the Tablelands Irrigation Scheme. Projected seasonal changes vary with a decrease in spring rainfall and increases in autumn and winter. Summer shows an increase to 2040, but a decrease after this to return to near current conditions by 2090.

Pertinent to the Tablelands scheme is the projected increases to rainfall in summer and autumn rainfall by 2040 in the upper Otara catchment. This is likely to result in increased flow in the Otara River over summer and autumn months.

By the 2090's, summer rainfall will be near to current levels while autumn rainfall will remain similar to that projected for 2040.

E.1.3.2 Heavy Rainfall Events

Most Otara River floods originate with air flow from the north or north-easterly direction.

The projected percentage changes in temperature for the Bay of Plenty (Table 0-10) have been used to derive the projected percentage increase in heavy rainfall, as detailed in Table 4 for 2040 and 2090.

Table 0-10 : Percentage Increase in Heavy Rainfall in Bay of Plenty

	2040					2090				
ARI (years)	Duration (hours)					Duration (hours)				
	1	**2**	**6**	**12**	**24**	**1**	**2**	**6**	**12**	**24**
10	6.7	6.5	6.1	5.9	5.7	15.5	15.1	14.3	13.7	13.2
20	6.9	6.8	6.7	6.6	6.5	16.2	16	15.5	15.3	15.1
50	7.2	7.2	7.2	7.2	7.2	16.8	16.8	16.8	16.8	16.8
100	7.2	7.2	7.2	7.2	7.2	16.8	16.8	16.8	16.8	16.8

Table 0-11 details the current and projected heavy rainfall design events for the upper Otara catchment. The results show that the frequency of a current 1 in 20-year, ARI heavy rainfall event will increase to around one in 10-years by 2090. The frequency of extreme rainfall events will double by 2090. A current 100-year ARI rainfall total of 267mm over 24 hours is projected to be a 50-year ARI event by 2090.

Table 0-11 : Heavy Rainfall Design Events (mm) – Upper Otara Catchment

	Duration (hours)					
ARI (years)	**1**	**2**	**6**	**12**	**24**	**48**
Current						
10	34	48	81	114	160	194
20	39	55	94	132	185	225
50	47	66	114	161	227	276
100	55	78	134	189	267	326
2040						
10	36	51	86	121	169	205
20	42	58	100	140	197	239
50	50	71	122	172	243	295
100	59	83	144	203	286	349
2090						
10	39	55	93	130	181	219
20	45	63	108	152	213	259
50	55	77	133	188	265	321
100	64	91	156	221	312	381

It isn't clear whether there could be increased numbers of tropical cyclones and periods of intensive storminess, but it is possible such changes could occur.

E.1.3.3 Air Temperature

Projections of changes in mean seasonal and annual temperature for the Bay of Plenty are detailed in Table 0-12 (MfE 2008).

Table 0-12 : Average Projected Change in Mean Annual and Seasonal Temperature (°C)

Season	2040	2090
Summer	1.0	2.2
Autumn	1.0	2.2
Winter	0.9	2.0
Spring	0.8	1.8
ANNUAL	0.9	2.1

In comparison to the current climate it is projected that by 2040 there will 10 to 15 more days when the temperature will exceed 25°C (MfE 2008, Mullan et al 2001). By 2090 there is projected to be 25 to 35 days more above 25°C.

Frosts (or days where temperature is less than 0°C) are expected to decrease in Tablelands area. Reductions of 5 fewer days of frost by 2050 and up to 10 fewer days by 2100 (Mullan et al 2001) are expected.

E.1.3.4 River Flow

Flow patterns in the Otara River show that highest mean flows are reached in the winter months and the lowest flows are experienced in autumn.

Projected changes to seasonal rainfall would suggest that Otara River flows are likely to be slightly higher in 2040 and 2090 during the irrigation seasons of summer and autumn.

E.1.3.5 Drought

PED for an average year in the area of the Tablelands scheme is projected to increase from the current 100mm by between 30 to 60mm by 2080. A PED with a 20-year ARI (or return period) is used to describe extreme drought conditions.

Table 0-13 details the PED with a 1 in 20-year ARI for the area (Mullan et al 2005). This 20-year ARI PED value is 200mm. Projections of the change to this in 2030 and 2080 are shown in the table for two downscaled global climate models: “low-medium” and, “medium-high” (Mullan et al 2005).

Table 0-13 : Current One in 20-Year ARI PED at Opotiki and Projected Changes

	PED (mm)		Average ARI for current 20-year drought	
Current	***2030 Low-Medium***	***2030 Low-High***	***2030 Low-Medium***	***2030 Low-High***
200mm	300	400	10	6
Current	***2080 Low-Medium***	***2080 Low-High***	***2080 Low-Medium***	***2080 Low-High***
200mm	300	500	10	5

Projections for 2030 show the current 20-year ARI PED of 200mm to increase to 300 to 400mm based on the two models. A PED of 200mm increases in frequency of occurrence from a one in 20-year ARI to around a one in 10-year ARI event. By 2080, a 20-year ARI PED is estimated to be 300 to 500mm. The one in 20-year ARI PED (200mm) increases in frequency to a one in 5 to a one in 10-year ARI.

The PED results presented are for unirrigated pasture. They therefore give an indication that within the Tablelands scheme an increase in irrigation will be necessary to offset the increases in PED.

Projected increases in the frequency of repeat drought events have been calculated (EcoClimate 2008). A PED drought threshold of 200mm has been used and the results presented in Table 0-14. The frequency of repeat droughts of this magnitude in the Opotiki area is currently 6%. The frequency is projected to increase to around 15 to 21% by 2030, and to between 19 and 30% by 2080.

Table 0-14 : Chance of Repeat Annual Occurrence of PED of 200mm in Opotiki

Current	2030 Low-Medium	2030 Medium-High	2080 Low-Medium	2080 Medium-High
6%	15%	21%	19%	30%

E.1.3.6 Groundwater Levels and Saltwater Intrusion

Projected sea level rise will increase the pressure of the salt water intrusion under the plains close to the coast. The rise in sea levels will cause groundwater level to rise – perhaps to nuisance levels requiring drainage for those properties nearest to the coast. Irrigated water and more frequent intense rainfall could potentially add to the problem and not drain away freely.

There is also a risk of salination due to the build up of salts in the groundwater, as has occurred on lower parts of the Rangitaiki Plains behind the coastal dunes.

The irrigation water used within the scheme is sourced from the Otara River so there will be no adverse effects on the quality of the irrigation water.

E.1.3.7 Wind Speed and Direction

Increased westerlies have been detailed as one reason for the drying trend in the Bay of Plenty since 1951 (Griffiths et al 2003).

E.1.3.8 Water Temperatures

At Opotiki it is projected that the average air temperature will increase 0.9°C above current levels by 2040 and 2.1°C by 2090. An increase in average water temperature of streams and rivers is also projected, but the magnitude of that change is subject to a number of factors including stream base flows and water depths and intactness of riparian vegetation.

Projected summer flows in the Otara River are similar or marginally higher than at present and are not expected to contribute to increased water heating in summer. The headwater tributaries which form the Otara River drain a forested catchment in the foothills of the Kahikatea Range. However, the lower catchment in the vicinity of Otara has been cleared and developed for pasture, with very little riparian vegetation remaining. Due to an almost total absence of shading of the bed the river is highly susceptible to warming in summer conditions. Revegetation of riparian areas will reduce summer heating to some extent but because the river is moderately wide the extent of shading that can be achieved is limited.

E.1.3.9 Water Quality and Aquatic Ecology

The Tablelands Irrigation Scheme draws its water at a rate of up to 270L/s from the lower reaches of the Otara River, some 8km from the sea, and pumps it through a rising main to a 500m^3 reservoir from where is it piped to recipients. Due to the limited storage capacity the demand for irrigation water is highest during periods of dry summer weather when the river flow is low. Over the next 80 years summer and autumn rainfall is projected to increase slightly above present levels while the risk of drought is also projected to increase.

The projected increase in average air temperatures will contribute to further increases in summer heating of rivers in the Bay of Plenty. The Otara River, which runs through a deforested lower catchment, and which has very little riparian vegetation in its lower reaches, is particularly susceptible to heating effects. Increased water temperatures together with higher carbon dioxide levels may increase the incidence of nuisance algae growth and associated water quality effects such as increasingly variable pH and dissolved oxygen regimes. The potential consequences for irrigation scheme infrastructure include increased clogging of screens and possibly increased pipe corrosion.

Potential adverse effects associated with summer heating of the Otara River may intensify the debate around a sustainable residual flow regime for the River and may potentially lead to a reduction in the amount of water available for irrigation at critical times. These issues may also lead to a renewed focus on remediation measures such as riparian planting programmes and targeted afforestation in erosion prone areas of the Otara catchment.

E.1.4 Southern Valleys Irrigation Scheme

E.1.4.1 Rainfall

A number of very strong rainfall gradients exist within the Wairau catchment. Orographic enhancement leads to greater rainfall totals (and intensities) in upper catchment areas and a general increase in the rainfall gradient from east to west. As little as 600mm of rainfall per year is received in low lying eastern areas near the coast, to in excess of 4000mm in the upper catchment areas to the west. There is also a gradient from northwest to southeast, with North-bank rainfalls in the Richmond Range averaging around 1600mm per year. South-bank catchments effectively lie in a rainshadow, receiving on average around 900mm per year.

The area around the scheme intake and Renwick experiences an average annual rainfall of 800mm.

Seasonal and annual rainfall projections are provided for three locations in and around the scheme catchment area. Projections are provided for Blenheim (taken from tabled results in MfE 2008) to represent the area that is irrigated by the scheme. Projections for the upper and mid-lower areas of the catchment above the scheme abstraction point are interpreted from maps of projected changes (MfE 2008).

Table 0-15 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090.

Table 0-15 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040			2090		
	Upper	Mid-Lower	Blenheim	Upper	Mid-Lower	Blenheim
Summer	-2	0	3	-2	3	5
Autumn	3	4	4	2	3	5
Winter	10	5	-1	10	6	1
Spring	6	2	-1	7	3	-1
ANNUAL	4	3	1	6	4	2

The projected changes to mean annual and seasonal rainfall show an overall increase over the entire Wairau catchment area above the Southern Valleys Irrigation Scheme. Up to 10% more rain is expected in winter and spring in the ranges of the upper Wairau catchment. Changes to Blenheim rainfall are small overall, although up to a 5% increase could be expected in summer and autumn.

Very prominent to the Southern Valleys scheme is the projected decrease (approximately 2%) in summer rainfall in the upper Wairau catchment. This could result in reduced flow in the Wairau River over summer months.

Table 0-16 : Projected Rainfall Totals at Blenheim Aero Raingauge (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Current	58	36	56	68	72	58	70	73	60	65	53	55	724
2040	60	37	58	71	75	57	69	72	59	64	52	57	733
2090	61	38	59	71	76	59	71	74	59	64	52	58	741

Seasonal rainfall totals and projected changes for the Blenheim Aero raingauge are detailed in Table 0-17. The projected changes are small.

Table 0-17 : Projected Seasonal Changes in Rainfall Totals at Blenheim (mm)

	Current	2040	*Difference*	2090	*Difference*
Summer	149	153	*4*	156	*7*
Autumn	196	204	*8*	206	*10*
Winter	201	199	*-2*	203	*2*
Spring	178	176	*-2*	176	*-2*
ANNUAL	724	733	*9*	741	*17*

E.1.4.2 Snow

Modelling of climate change impacts on snow (Hendrikz 2010) provides projections that the maximum annual snow water equivalence in the area will decrease significantly. At an elevation of 2200m (indicative of the highest elevations in the Wairau catchment) there is projected to be decreases of 10% by 2040 and 25% 2090. At lower elevations of 1500m the decreases are projected to be 25% and 45% respectively.

This will potentially impact on seasonal river flow in spring and early summer when snowmelt traditionally boosts flows.

E.1.4.3 Heavy Rainfall Events

Table 0-18 : Percentage Increase in Heavy Rainfall in Marlborough

	2040						2090					
ARI (years)	Duration (hours)						Duration (hours)					
	1	**2**	**6**	**12**	**24**	**48**	**1**	**2**	**6**	**12**	**24**	**48**
10	7.4	7.2	6.8	6.5	6.3	6.1	14.8	14.4	13.6	13	12.6	12.2
20	7.7	7.6	7.4	7.3	7.2	7.1	15.4	15.2	14.8	14.6	14.4	14.2
50	8	8	8	8	8	7.8	16	16	16	16	16	15.6
100	8	8	8	8	8	8	16	16	16	16	16	16

Table 0-19 details the current and projected heavy rainfall design events for the upper Wairau catchment. The results show that the frequency of a current one in 20-year ARI heavy rainfall event will increase to one in 10-years by 2090. The frequency of extreme rainfall event will double by 2090. A current 20-year ARI rainfall total of 219mm over 24 hours is projected to be a 10-year ARI event by 2090.

Table 0-19 : Heavy Rainfall Design Events (mm) – Upper Wairau Catchment

	Duration (hours)					
ARI (years)	**1**	**2**	**6**	**12**	**24**	**48**
Current						
10	28	43	83	127	193	257
20	33	50	96	145	219	294
50	42	62	118	176	264	354
100	51	75	140	207	307	413
2040						
10	30	46	89	135	205	273
20	36	54	103	156	235	314
50	45	67	127	190	285	382
100	55	81	151	223	331	446
2090						
10	32	49	95	143	217	289
20	38	58	110	166	251	335
50	48	72	137	205	306	409
100	59	87	162	240	356	479

E.1.4.4 River Flow

The catchment yield for the Wairau River is dominated by the yield from the upper reaches of the catchment. Flow patterns in the Wairau River show that highest mean flows are reached in the October and November months (when snowmelt is encouraged by warm north-westerly rain) and the lowest flows are experienced in February and March.

Projected changes to seasonal rainfall (Section E.1.4.1) would suggest that Wairau River flows are likely to increase in winter since there is expected to be an increase in winter rainfall and a relative increase in rain versus snow due to projected higher temperatures.

Changes to spring and summer flow patterns are unclear (EcoClimate 2008) because changes to snowmelt are quite complex and it is not known exactly how spring or summer flows may change. Section E.1.5.2 details projections of less snow in the future, so simplistically it could be reasoned that snow available to melt will be less and river flows will be lower due to this.

E.1.4.5 Air Temperature

Projections of changes in mean seasonal and annual temperature for Marlborough are detailed in Table 0-20 (MfE 2008).

Table 0-20 : Average Projected Change in Mean Annual and Seasonal Temperature (°C)

Season	2040	2090
Summer	1.0	2.1
Autumn	1.0	2.1
Winter	0.9	2.1
Spring	0.8	1.8
ANNUAL	0.9	2.0

In comparison to the current Marlborough climate it is projected that by 2040 there will 10 to 15 more days where the temperature will exceed 25°C (MfE 2008, Mullan *et al* 2001). By 2090 there are projected to be 15 to 25 days more above 25°C.

Frosts (or days where temperature is less than 0°C) are expected to decrease in Marlborough and the Wairau catchment. Reductions of 10 fewer days of frost by 2050 and 14 fewer days by 2100 (Mullan et al 2001) are expected.

E.1.4.6 Drought

The Wairau catchment, particularly in the valley and plain areas where the scheme is located, frequently has long period without rain.

PED for an average year in the area of the Southern Valleys scheme is projected to increase by between 120 to 150mm by 2080. A PED with a 20-year ARI (or return period) is used to describe extreme drought conditions.

Table 0-21 details the PED with a one in 20-year ARI for Blenheim (Mullan et al 2005). The 20-year ARI PED value is 895mm for Blenheim. Projections of the change to this in 2030 and 2080 are shown in the table for two downscaled global climate models: "low-medium" and "medium-high" (Mullan et al 2005).

Table 0-21 : Current One in 20-Year ARI PED at Blenheim and Projected Changes

	PED (mm)		Average ARI for current 20-year drought	
Current	***2030 Low-Medium***	***2030 Low-High***	***2030 Low-Medium***	***2030 Low-High***
895mm	930	980	15	10
Current	***2080 Low-Medium***	***2080 Low-High***	***2080 Low-Medium***	***2080 Low-High***
895mm	955	1035	12	7

Projections for 2030 show the current 20-year ARI PED of 895mm to increase to 930-980mm based on the two models. A PED of 895mm increases in frequency of occurrence from a one in 20-year ARI to a one in 15 to one in 10-year ARI event. By 2080, a 20-year ARI PED is estimated to be 955 to 1035mm. The one in 20-year ARI PED (895mm) increases in frequency to a one in 7 to a one in12-year ARI.

The PED results presented are for unirrigated pasture. They therefore give an indication that within the Southern Valleys scheme an increase in irrigation will be necessary to offset the increases in PED.

Projected increases in the frequency of repeat drought events have been calculated (EcoClimate 2008). A PED drought threshold of 400mm has been used and the results presented in Table 0-22. The frequency of repeat droughts of this magnitude in Blenheim is currently 16%. The frequency is projected to increase to around 23% by 2030, and to between 25 and 31% by 2080.

Table 0-22 : Chance of Repeat Annual Occurrence of PED of 400mm in Marlborough

Current	2030 Low-Medium	2030 Medium-High	2080 Low-Medium	2080 Medium-High
16%	22%	24%	25%	31%

E.1.4.7 Sediment or Erosion Issues

As the intake for the Southern Valleys scheme is just downstream of the Waihopai and Wairau river confluence, the degree of sediment influence is greatly affected by the braiding pattern of the river (Marlborough District Council, pers. comm. 2010). The Waihopai River carries more sediment than the Wairau River, so the irrigation intake will have more sediment when fed primarily by Waihopai water. This is what is currently occurring. If the proportion of Wairau water increases in the future, the extent of sediment at the intake may reduce.

E.1.4.8 Wind Speed and Direction

Wind typically plays an important role in evapo-transpiration, by increasing turbulence and facilitating the movement of moisture-laden air into the drier atmosphere. Wind increases the loss of moisture from wet surfaces, but where there is no moisture, for example in a very dry paddock, little additional loss of moisture may occur. Therefore, if windiness increases with climate change, it is likely to increase moisture loss within the Southern Valleys' Irrigation Scheme where moisture is still available due to irrigation.

E.1.4.9 Water Temperatures

In Marlborough it is projected that the average air temperature will increase 0.9°C above current levels by 2040 and 2.0°C by 2090. An increase in average water temperature of streams and rivers is also projected, but the magnitude of that change is subject to a number of factors including stream base flows and water depths and intactness of riparian vegetation.

The projected changes to mean and seasonal rainfall over the entire Wairau catchment indicate that river flows will increase in winter. Changes in spring and summer are unclear, but potentially there will be less flow in summer, which may make a minor contribution to increased summer heating. The headwater tributaries which form the Wairau River drain alpine and subalpine forested catchments in the St Arnaud and Raglan Ranges. However, the middle and lower Wairau is a broad braided river which is too wide to be effectively shaded by riparian vegetation. The middle and lower reaches are thus susceptible to warming in summer conditions.

E.1.4.10 Water Quality and Aquatic Ecology

Water is sourced from the Wairau River immediately below the confluence with the Waihopai River at a rate of up to 1000L/s. The water flows from the river into a settlement pond and then via a new water race into Gibsons Creek. Water abstracted from Gibson Creek and delivered by pipe to end users. Due to the limited storage capacity the demand for irrigation water is highest during periods of dry summer weather when the river flow is low. A projected increase in drought risk in the area serviced by the scheme suggests demand for irrigation water will increase. Projected changes to seasonal rainfall suggest river flows in the Wairau could be higher in winter and early spring, but possibly lower in summer and autumn. There is therefore a possibility of an increasing demand for a diminishing resource.

The projected increase in average air temperatures and an increasing number of days above 25 ^{o}C is expected to increase summer heating of rivers in Marlborough. The Wairau River is too wide to be effectively shaded by riparian vegetation and so is susceptible summer heating, particularly during periods of drought when flows recede to low levels. Increased water temperatures together with higher carbon dioxide levels may increase the incidence of nuisance algae growth and associated water quality effects such as increasingly variable pH and dissolved oxygen regimes. The consequences for irrigation scheme infrastructure include increased clogging of screens and possibly increased pipe corrosion.

Didymo was confirmed in the Wairau in 2008 but hasn't yet been observed at nuisance levels. There is some evidence of a survival limit for this species at a mean air temperature in the coolest month of ~5.5 ^{o}C, i.e., this species may not be able to maintain a presence if temperatures increase above this level (although this is yet to be proven).

Potential adverse effects associated with summer heating and reduced summer flows in the Wairau River may intensify the debate around a sustainable residual flow regime for the River and may potentially lead to reduced availability of water for irrigation at critical times.

Increased erosion and sediment yield from the catchment associated with more frequent heavy rainfall events may lead to increased sediment loads in the river, with possible consequences for maintenance of irrigation scheme infrastructure.

E.1.5 Waimakariri Irrigation Scheme

E.1.5.1 Rainfall

Seasonal and annual rainfall projections are provided for the upper catchment area of the Waimakariri River (Southern Alps) and for Christchurch. The figures for the headwaters area are interpolated from nationwide maps of projected changes to rainfall.

Table 0-23 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090 (MfE 2008).

Table 0-23 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040		2090	
	Headwaters	Christchurch	Headwaters	Christchurch
Summer	-1	2	-3	3
Autumn	3	5	0	6
Winter	10	-8	15	-11
Spring	7	-1	10	-2
ANNUAL	6	-1	8	-2

The projected changes to mean annual rainfall for the headwaters of the Waimakariri River show an overall increase. Summer totals are projected to decrease by 1% and 3% for 2040 and 2090 respectively, but all other seasons show increasing rainfall in the upper catchment. Winter and spring are likely to have the largest increases.

E.1.5.2 Snow

Modelling of climate change impacts on snow (Hendrikz 2010) provides projections that the maximum annual snow water equivalence in the area will decrease significantly. At an elevation of 2200m (indicative of the higher elevations in the Waimakariri catchment) there are projected to be decreases of 10% by 2040 and 25% 2090. At lower elevations of 1500m the decreases are projected to be 25% and 45% respectively.

This is a marked change and will impact on seasonal river flow in spring and early summer when snowmelt traditionally boosts flows.

E.1.5.3 Heavy Rainfall Events

The projected percentage changes in temperature for the Canterbury region (Table 0-26) have been used to derive the projected percentage increase in heavy rainfall, as detailed in Table 0-24 for 2040 and 2090.

Table 0-24 : Percentage Increase in Heavy Rainfall in Canterbury

	2040						**2090**					
ARI (years)	Duration (hours)						Duration (hours)					
	1	**2**	**6**	**12**	**24**	**48**	**1**	**2**	**6**	**12**	**24**	**48**
10	7.0	6.8	6.5	6.2	6.0	5.8	15.5	15.1	14.3	13.7	13.2	12.8
20	7.3	7.2	7.0	6.9	6.8	6.7	16.2	16.0	15.5	15.3	15.1	14.9
50	7.6	7.6	7.6	7.6	7.6	7.4	16.8	16.8	16.8	16.8	16.8	16.4
100	7.6	7.6	7.6	7.6	7.6	7.6	16.8	16.8	16.8	16.8	16.8	16.8

Table 0-25 details the current and projected heavy rainfall design events for the upper Waimakariri catchment. The results show that the frequency of a current one in 20-year ARI heavy rainfall event will increase to around one in 10-years by 2090. A current 20-year ARI rainfall total of 380mm over 24 hours is projected to be a 10-year ARI event by 2090.

Table 0-25 : Heavy Rainfall Design Events (mm) – Waimakariri Catchment

	Duration (hours)					
ARI (years)	**1**	**2**	**6**	**12**	**24**	**48**
Current						
10	48	73	144	221	339	484
20	53	82	161	248	380	548
50	63	96	189	290	444	650
100	71	109	214	328	503	744
2040						
10	51	78	153	234	359	512
20	57	88	173	265	406	585
50	67	103	203	312	478	698
100	76	117	230	353	542	800
2090						
10	55	84	164	251	383	546
20	62	95	186	286	437	630
50	73	112	221	338	519	756
100	83	127	250	383	588	869

E.1.5.4 River Flow

The flow for the Waimakariri River is derived from precipitation in the upper catchment. In winter much of this falls as snow and is not released to the river until the spring thaw. As such there is a strong seasonal pattern to river flows in the Waimakariri River, with higher flows from September to December as the snow melts. February and March have the lowest flows.

Projected changes to seasonal rainfall (Section E.1.5.1) would suggest that Waimakariri River flows could increase in winter and spring because there is expected to be an increase in rainfall for these seasons in the headwaters.

Changes to spring and summer flow patterns due to snowmelt are quite complex to determine (EcoClimate 2008). Section E.1.5.2 details future projections of less snow, so simplistically it could be reasoned that there will be less snow available to melt and therefore river flows could be lower due to this. However, this isn't clear if it could be offset by the projected increases in seasonal rainfall for winter and spring.

E.1.5.5 Air Temperature

Projections of changes in mean seasonal and annual temperature for the upper catchment area of the Waimakariri River and for Canterbury overall are detailed in Table 0-26 (MfE 2008).

Table 0-26 : Average Projected Change in Mean Annual and Seasonal Temperature (°C) – Lower and Upper Limits in Brackets

Season	2040		2090	
	Headwaters	Canterbury	Headwaters	Canterbury
Summer	1.0	0.9	2.3	2.1
Autumn	1.0	0.9	2.2	2.1
Winter	1.0	1.0	2.3	2.2
Spring	0.7	0.8	1.8	1.8
ANNUAL	1.0	0.9	2.1	2.0

In comparison to the current climate it is projected that by 2040 there will 7 to 10 more days where the temperature will exceed 25°C (MfE 2008, Mullan et al 2001). By 2090 there is projected to be 12 to 20 days more above 25°C.

Frosts (or days where temperature is less than 0°C) are expected to decrease in the area of the irrigation scheme. Reductions of 10 fewer days of frost by 2050 and 15 to 20 fewer days by 2100 (Mullan et al 2001) are expected.

E.1.5.6 Drought

Changes in drought risk are generally caused by extended periods of no, or very limited, rainfall.

The projected increase in temperature and wind on the Canterbury Plains will result in increased evapo-transpiration.
Table 0-23 shows potential increases in summer and autumn rainfall for Christchurch (which is applicable to the area served by the Waimakariri Irrigation Scheme) but frequency of drought is projected to increase.

Table 0-27 details the PED with a one in 20-year ARI for Darfield (Mullan et al 2005), which is around 15km southwest of the irrigation area. This 20-year ARI PED value is 465mm. Projections of the change to this in 2030 and 2080 are shown in the table for two downscaled global climate models: “low-medium” and, “medium-high” (Mullan et al 2005).

Table 0-27 : Current one in 20-Year ARI PED at Darfield and Projected Changes

	PED (mm)		Average ARI for current 20-year drought	
Current	***2030 Low-Medium***	***2030 Low-High***	***2030 Low-Medium***	***2030 Low-High***
465mm	500	550	15	8
Current	***2080 Low-Medium***	***2080 Low-High***	***2080 Low-Medium***	***2080 Low-High***
465mm	515	650	11	4

Projections for 2030 show the current 20-year ARI PED of 465mm to increase to around 500 to 550mm based on the two models. A PED of 465mm increases in frequency of occurrence from a one in 20-year ARI to around a one in 8 to a one in 15-year ARI event. By 2080, a 20-year ARI PED is estimated to be around 515 to 650mm. The one in 20-year ARI PED increases in frequency to around a one in 4 to a one in 11-year ARI.

The PED results presented are for unirrigated pasture. They therefore give an indication that within the Waimakariri scheme an increase in irrigation will be necessary to offset the increases in PED.

Projected increases in the frequency of repeat drought events have been calculated (EcoClimate 2008). Two PED drought thresholds of 200mm and 400mm have been analysed and the results presented in Table 0-28. The frequency of repeat droughts of these magnitudes in the irrigation scheme area is currently 60% (200mm) and 12% (400mm).

Table 0-28 : Chance of Repeat Annual Occurrence of PED of 200 and 400mm in Canterbury (EcoClimate 2008)

PED	Current	2030 Low-Medium	2030 Medium-High	2080 Low-Medium	2080 Medium-High
200mm	60%	74%	78%	79%	85%
400mm	12%	12%	23%	25%	39%

E.1.5.7 Sediment or Erosion Issues

Soil erosion on the plains is more likely due to stronger winds and more heat.

E.1.5.8 Groundwater Levels

The shallow aquifers associated with the Eyre River (Eyre River Zone) are usually the most affected by dry winters.
Table 0-23 shows projected decreases in winter rainfall of around 10% due to climate change.

During drought years, groundwater levels in the Ashley- Waimakariri zone (and flows in the associated spring fed streams such as the Cam River) mainly depend on whether or not the Ashley River goes dry in the Rangiora area in summer, and the duration of this drying.

E.1.5.9 Wind Speed and Direction

Wind typically plays an important role in evapo-transpiration, by increasing turbulence and facilitating the movement of moisture-laden air into the drier atmosphere. Wind increases the loss of moisture from wet surfaces, but where there is no moisture, for example in a very dry paddock, little additional loss of moisture may occur. Therefore, if windiness increases with climate change, it is likely to increase moisture loss within the Waimakariri Irrigation Scheme where moisture is still available due to irrigation.

E.1.5.10 Water Temperatures

In the headwaters of the Waimakariri River it is projected that the average air temperature will increase 1°C above current levels by 2040 and 2.1°C by 2090. Projected increases are marginally lower in Canterbury (0.9°C by 2040 and 2.0°C by 2090). An increase in average water temperature of rivers and water races is also projected, but the magnitude of that change is subject to a number of factors including any changes in river base flows and the intactness of riparian vegetation.

It is projected that Waimakariri River flows will increase in winter and spring but a reduced snow melt season may result in lower flows in early summer, with little change from present in autumn. The headwaters of the Waimakariri River drain alpine areas and subalpine forested catchments in the Southern Alps and adjacent ranges. For much of its length, the Waimakariri is a broad braided river which is too wide to be effectively shaded by riparian vegetation. The middle and lower reaches on the Canterbury Plains are thus susceptible to warming in summer conditions.

The 250km of irrigation races which spread across the Plains between the Waimakariri and Ashley Rivers are for the most part running across open farmland with little or no overhead shading. These are relatively low gradient watercourses in which water can take up to 48 hours to travel from the river to the end user. They are therefore susceptible to warming in summer conditions.

E.1.5.11 Water Quality and Aquatic Ecology

Water is sourced from the Waimakariri River immediately below the Waimakariri Gorge at a rate of up to 10,500L/s. A traditional intake structure leads to settling ponds. Numerous distribution races feed the rest of the scheme. Due to the limited storage capacity the demand for irrigation water is highest during periods of dry summer weather when the river flow is low. A projected increase in drought risk in the area serviced by the scheme suggests an increased demand for irrigation water in the future. Projected changes to seasonal precipitation suggest river flows in the Waimakariri could be higher in winter and early spring, but lower in summer and unchanged in autumn. There is therefore a possibility of an increasing demand for a diminishing resource during the summer period.

The projected increase in average air temperatures and an increasing number of days above 25^{o}C is expected to increase summer heating of the Waimakariri River. The River is too wide to be effectively shaded by riparian vegetation and so is susceptible to heating, particularly during periods of summer drought when flows recede to low levels. Increased water temperatures together with higher carbon dioxide levels may increase the incidence of nuisance algae growth and associated water quality effects such as increasingly variable pH and dissolved oxygen regimes. The consequences for irrigation scheme infrastructure include increased clogging of screens and possibly increased pipe corrosion.

Didymo has not been recorded in the Waimakariri River although Kilroy (2007) identified it as a river with close to optimal conditions, and thus susceptible to invasion. The expected warmer conditions may reduce its susceptibility in the future. There is some evidence of a survival limit for this species at a mean air temperature in the coolest month of ~5.5^{o}C, i.e., this species may not be able to maintain a presence in those parts of the river where temperatures increase above this level (although this is yet to be proven).

Potential adverse effects associated with summer heating and reduced summer flows in the Waimakariri River may contribute to the already intense debate around a sustainable residual flow regime for the River and may potentially lead to reduced availability of water for irrigation at critical times unless more storage can be provided.

E.1.6 Manuherikia Irrigation Scheme

E.1.6.1 Rainfall

Annual rainfall in the area of the Manuherikia irrigation scheme ranges between 350 to 400mm.

Seasonal and annual rainfall projections due to climate change are provided for the Manuherikia area. Table 0-29 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090 (MfE 2008).

Table 0-29 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040		2090	
	Manuherikia	Queenstown	Manuherikia	Queenstown
Summer	3	1	5	1
Autumn	2.5	2	3	2
Winter	10	16	20	29
Spring	4	8	8	15
ANNUAL	5	7	7	12

The projected changes to mean annual rainfall show an increase across all seasons over the Manuherikia catchment area. Projected seasonal changes vary with small projected increases in summer and autumn, and relatively large increases in winter and spring. Winter rainfall is projected to increase significantly – up to 20% by 2090.

E.1.6.2 Snow

Modelling of climate change impacts on snow (Hendrikz 2010) provides projections that the maximum annual snow water equivalence in the area will decrease significantly. At elevations of 1600 to 1800m (indicative of the high elevations in the Manuherikia catchment) there are projected to be decreases of 20% by 2040 and 40% by 2090. This is a marked change and will impact on seasonal river flow in spring and early summer when snowmelt traditionally boosts flows.

E.1.6.3 Heavy Rainfall Events

The projected percentage changes in temperature for the Otago (Table 0-32) have been used to derive the projected percentage increase in heavy rainfall, as detailed in Table 0-30 for 2040 and 2090.

Table 0-30 : Percentage Increase in Heavy Rainfall in Otago

	2040						2090					
ARI (years)	Duration (hours)						Duration (hours)					
	1	2	6	12	24	48	1	2	6	12	24	48
10	6.7	6.5	6.1	5.9	5.7	5.5	14.8	14.4	13.6	13.0	12.6	12.2
20	6.9	6.8	6.7	6.6	6.5	6.4	15.4	15.2	14.8	14.6	14.4	14.2
50	7.2	7.2	7.2	7.2	7.2	7.0	16.0	16.0	16.0	16.0	16.0	15.6
100	7.2	7.2	7.2	7.2	7.2	7.2	16.0	16.0	16.0	16.0	16.0	16.0

The projected percentage increases are applied to design rainfall in the Manuherikia catchment, as detailed in Table 0-31, and the results show that the frequency of a current one in 20-year ARI heavy rainfall events will increase to around one in 10-years by 2090. The frequency of extreme rainfall event will essentially double by 2090. A current 20-year ARI rainfall total of 66mm over 24 hours is projected to be a 10-year ARI event by 2090.

Table 0-31 : Heavy Rainfall Design Events (mm) – Manuherikia Catchment

	Duration (hours)					
ARI (years)	**1**	**2**	**6**	**12**	**24**	**48**
Current						
10	17	22	34	44	58	68
20	21	27	40	51	66	77
50	29	36	51	64	81	94
100	38	46	64	78	95	110
2040						
10	18	23	36	47	62	72
20	22	28	43	55	71	82
50	31	38	55	69	86	100
100	41	50	68	83	102	118
2090						
10	19	25	38	50	66	76
20	24	31	46	59	76	88
50	33	42	60	75	93	108
100	44	54	74	90	110	128

E.1.6.4 Air Temperature

Projections of changes in mean seasonal and annual temperature for Otago are detailed in Table 0-32 (MfE 2008).

Table 0-32 : Average Projected Change in Mean Annual and Seasonal Temperature (°C)

Season	2040	2090
Summer	0.9	2.0
Autumn	0.9	2.0
Winter	1.0	2.2
Spring	0.7	1.7
ANNUAL	0.9	2.0

In comparison to the current climate it is projected that by 2040 there will 5 more days where the temperature will exceed 25 °C (MfE 2008, Mullan et al 2001). By 2090 there is projected to be 5 to 10 days more above 25 °C.

Frosts (or days where temperature is less than 0 °C) are expected to decrease in the Manuherikia area. Reductions of 10 fewer days of frost by 2050 and 20 fewer days by 2100 (Mullan et al 2001) are expected.

E.1.6.5 Drought

Changes in drought risk are generally caused by extended periods of no, or very limited, rainfall.

As detailed in Section E.1.6.1, rainfall is projected to increase overall in the Manuherikia catchment area. This increase in rainfall could be expected to counteract the projected increase in temperature and subsequent increase in evapo-transpiration. However, the frequency of drought is projected to increase.

PED for an average year in the area of the Manuherikia scheme is projected to increase from the current 500mm to 600mm by 2080. A PED with a 20-year ARI (or return period) is used to describe extreme drought conditions.

Table 0-33 details the PED with a 1 in 20-year ARI for the area (Mullan et al 2005). This 20-year ARI PED value is 645mm. Projections of the change to this in 2030 and 2080 are shown in the table for two downscaled global climate models: “low-medium” and, “medium-high” (Mullan et al 2005).

Table 0-33 : Current 1 in 20-Year ARI PED in Otago and Projected Changes

	PED (mm)		**Average ARI for current 20-year drought**	
Current	***2030 Low-Medium***	***2030 Low-High***	***2030 Low-Medium***	***2030 Low-High***
645mm	700	700	12	10
Current	***2080 Low-Medium***	***2080 Low-High***	***2080 Low-Medium***	***2080 Low-High***
645mm	700	725	8.5	6.5

Projections for 2030 show the current 20-year ARI PED of 645mm to increase to 700mm based on the two models. A PED of 645mm increases in frequency of occurrence from a 1 in 20-year ARI to around a 1 in 10-year ARI event. By 2080, a 20-year ARI PED is estimated to be around 725mm. The 1 in 20-year ARI PED increases in frequency to around a 1 in 7-year ARI.

The PED results presented are for unirrigated pasture. They therefore give an indication that within the Tablelands scheme an increase in irrigation will be necessary to offset the increases in PED.

Projected increases in the frequency of repeat drought events have been calculated (EcoClimate 2008). Two PED drought thresholds of 200mm and 400mm have been used and the results presented in Table 0-34. The frequency of repeat droughts of these magnitudes in the Manuherikia area is currently 34% (200mm) and 9% (400mm).

The results show the frequency does not increase much due to projected climate change. The frequency of occurrence of consecutive 400mm PED drought events is projected to increase from 34% to 35% by 2030, and to around 40% by 2080.

Table 0-34 : Chance of Repeat Annual Occurrence of PED of 200 and 400mm in Otago

PED	Current	2030 Low-Medium	2030 Medium-High	2080 Low-Medium	2080 Medium-High
200mm	34%	36%	36%	40%	42%
400mm	9%	11%	11%	12%	15%

E.1.6.6 Groundwater Levels

Groundwater in the Manuherikia catchment is recharged from a combination of flow from surface water, rainfall and irrigation return water (Bekesi 2005). The groundwater resource also contributes flow to the Manuherikia River.

Projected increases in mean rainfall in the catchment should increase the reliability of recharge to the groundwater resource. In turn, this will also help to maintain the groundwater contribution to the Manuherikia River – from which irrigation scheme water is sourced.

E.1.6.7 Water Temperatures

In the Manuherikia area it is projected that the average air temperature will increase 0.9°C above current levels by 2040 and 2.0°C by 2090. An increase in average water temperature is also projected, but the magnitude of that change will be moderated to some extent by the projected increase in river flows. The headwater tributaries which form the Manuherikia River drain the high country tussock grassland and alpine areas of Hawkdun and Bathans Ranges. The middle and lower Manuherikia is a broad braided river which is too wide to be effectively shaded by riparian vegetation. The river is expected therefore to remain moderately susceptible to warming in summer conditions.

Water in the Manuherikia main race is mostly un-shaded by riparian vegetation and is susceptible to summer heating.

The Falls Dam reservoir is situated at an elevation of approximately 580m above sea level and is fed by watercourses draining alpine areas. The average water temperature is likely increase in line with air temperatures.

E.1.6.8 Water Quality and Aquatic Ecology

Water is sourced from the Manuherikia River in the Ophir Gorge and from Chatto Creek at a rate of up to 2380L/s. The scheme includes storage at the Falls Dam but nevertheless the demand for irrigation water is highest during periods of dry summer weather when the river flow is low. A projected increase in drought risk in the area serviced by the scheme suggests demand for irrigation water will increase. Projected river flows are higher across all seasons which in combination with the storage at Falls Dam may go some way to meet the expected increased demand.

The projected increase in average air temperatures and an increasing number of days above 25 ^{o}C is expected to increase summer heating of the River, water races and to a lesser extent in the Falls Dam reservoir. Increased water temperatures together with higher carbon dioxide levels may increase the incidence of nuisance weed and algae growth, and associated water quality effects such as increasingly variable pH and dissolved oxygen regimes. The consequences for irrigation scheme infrastructure include increased clogging of screens and possibly increased pipe corrosion. The risk of pest fish becoming established in the Falls Dam reservoir is probably not significantly increased as this will continue to be a cold water system.

Didymo was confirmed in the Manuherikia River in February 2007 but has not yet been observed at nuisance levels. There is some evidence of a survival limit for this species at a mean air temperature in the coolest month of ~5.5°C, i.e., this species may not be able to maintain a presence if temperatures increase above this level (although this is yet to be proven).

Potential adverse effects associated with summer heating in the Manuherikia River may intensify the debate around a sustainable residual flow regime for the River. However, as flows are projected to increase it seems unlikely that the river ecology will come under significantly more stress than at present.

E.2 Rural Water Supply Case Study Analyses

E.2.1 General

There are a number of projected climatic changes that are common to each of the rural water supply stock water schemes, as outlined below.

E.2.1.1 Rainfall

Climate change is expected to increase the risk of heavy rainfall, and consequently flood risk. A warmer atmosphere can hold more moisture – about 8% for every 1 °C increase in temperature (MfE 2008) – and therefore more water is available to be dumped as rain over short periods. This applies even where seasonal or annual rainfall is projected to decrease.

Applying the screening assessment, as per MfE (2008) guidance, with mid-range climate change projections, the frequency of high intensity rainfall events in each of the rural water supply catchment areas is expected to increase about two-fold due to climate change. For example a heavy rainfall event that currently has a one in 20-year average recurrence interval will increase to around one in 10-years by 2090.

E.2.1.2 Sediment or Erosion Issues

The projected increase in the frequency and magnitude of heavy rainfall events is likely to lead to increased sediment yields from erosion prone areas within each catchment. This may result in increased sediment loads in water taken by the schemes, with potential implications for the level of treatment required for water supply.

E.2.1.3 Wind Speed and Direction

Changes in wind speed have been modelled for climate change projections. Future scenarios show a strong bias towards increasing westerly flow, particularly in autumn and winter (Pearce et al 2005).

Results suggest that the mean westerly component will increase by about 10% of its current values within the next 50 years (MfE 2008).

Wind typically plays an important role in evapo-transpiration, by increasing turbulence and facilitating the movement of moisture-laden air into the drier atmosphere.

E.2.2 Cold Creek RWS

E.2.2.1 Rainfall

Seasonal and annual rainfall projections are provided for the Cold Creek catchment area above the scheme abstraction (MfE 2008). Table 0-35 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090.

Table 0-35 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040	2090
Summer	-1	-3
Autumn	3	1
Winter	5	8
Spring	0	1
ANNUAL	2	3

Summer rainfall is projected to decrease slightly, which could result in lower flows in Cold Creek during the summer months.

E.2.2.2 Air Temperature

Projections of changes in mean seasonal and annual temperature for the Taranaki region are detailed in Table 0-36 (MfE 2008).

Table 0-36 : Average Projected Change in Mean Annual and Seasonal Temperature (°C) – Lower and Upper Limits in Brackets

Season	2040	2090
Summer	1.1 *(0.2, 2.4)*	2.3 *(0.9, 6.1)*
Autumn	1.0 *(0.2, 2.6)*	2.2 *(0.6, 5.3)*
Winter	0.9 *(0.1, 2.2)*	2.1 *(0.5, 5.1)*
Spring	0.8 *(0.0, 2.0)*	1.8 *(0.3, 4.9)*
ANNUAL	0.9 *(0.2, 2.3)*	2.1 *(0.6, 5.3)*

In comparison to the current climate it is projected that by 2040 there will 5 to 10 more days where the temperature will exceed 25°C (MfE 2008, Mullan et al 2001). By 2090 there is projected to be 10 to 20 days more above 25°C.

Projected changes to days with frost (or days where temperature is less than 0°C) show a reduction of 5 days in both 2050 and 2100 (Mullan et al 2001).

E.2.2.3 Drought

Changes in drought risk are generally caused by extended periods of no, or very limited, rainfall.

Mullan et al (2005) adopt the potential evapo-transpiration deficit (PED) as a measure of drought or water deficit. This measurement incorporates the climatic factors of rainfall, temperature and wind.

PED is calculated for unirrigated land and is measured in millimetres. It can be thought of as the amount (depth) of water needed to supply a crop, in addition to actual rainfall. A PED of 200mm over a growing season could be overcome by applying 200mm of irrigation water at appropriate times.

A PED with a 20-year ARI (or return period) is used to describe extreme drought conditions. PEDs of 50mm and 150 to 300mm are estimated as the 20-year ARI drought event respectively for the Cold Creek catchment area and the area served by the scheme.

Table 0-37 details projected changes to the one in 20-year ARI PED as interpreted from Mullan et al (2005). The frequency of extreme drought is not expected to change for the catchment area above the scheme (Mt Taranaki), however the frequency for the area served by scheme increases to one in 10 to 20-years in 2030 and 5 to 10-year in 2080.

Table 0-37 : Projected Frequency of Current 1 in 20-Year ARI PED Drought – Cold Creek RWS

Year	Source Catchment Area	Scheme Area
2030	20-year	10 to 20-year
2080	20-year	5 to 10-year

Projected increases in the frequency of repeat drought events have been calculated (EcoClimate 2008).

A PED drought threshold of 200mm (equal to approximately a 20-year ARI in the scheme area) currently has around a 2% chance of a repeat annual occurrence. This is projected to increase only a very minor amount to 3% by 2030 and around 7% by 2080.

E.2.2.4 Wind Speed and Direction

A study into the region's rainfall between 1930 and 2004 found that there has already been an increase in westerly winds over this period (TRC 2009).

E.2.2.5 Water Temperatures

Average air temperature in the Taranaki Region it is projected to increase 0.9 °C above current levels by 2040 and 2.1 °C by 2090. An increase in average water temperature of rivers is also projected, but the magnitude of that change is subject to a number of factors including river base flows, water depth and the intactness of riparian vegetation.

Cold Creek is a spring feed stream which originates under dense forest cover on the slopes of Mount Taranaki at an elevation of around 700m. It has historically had a year round average temperature of 9^{o}C, hence its name. Riparian vegetation provides almost complete shade in the upper reaches but becomes patchy in the middle and lower reaches below an elevation of 400m. Average flows in Cold Creek are projected to increase in autumn and winter but may be slightly lower in summer. These factors suggest that Cold Creek is not particularly susceptible to summer heating, and that future changes to the temperature regime will be modest.

E.2.2.6 Water Quality and Aquatic Ecology

Water is sourced from Cold Creek approximately 1000m downstream from the Egmont National Park boundary at a rate of just under 50L/s. The intake structure consists of a weir with a side chamber. Water is delivered by pipe to a concrete settling tank followed by dosing with lime alum and chlorine prior to a sand filter and then a 4500m^3 reservoir. It is then conveyed via 300mm pipe to recipients.

A projected increase in drought risk in the area serviced by the scheme suggests water demand will increase. Projected changes to seasonal rainfall suggest river flows could be higher in autumn and winter but slightly lower in summer. There is therefore a possibility of an increasing demand during summer when flows may be reduced.

Water temperatures may be higher than at present but are unlikely to increase to the extent that they cause adverse effects on the stream ecology, or for the irrigation scheme. If this were to become an issue effective remediation could be achieved by riparian planting along the middle and lower reaches of the Creek.

Increased erosion and sediment yield from the catchment associated with more frequent heavy rainfall events will lead to increased sediment loads in the Creek, with possible consequences for maintenance of irrigation scheme infrastructure.

E.2.3 Hunterville RWS

E.2.3.1 Rainfall

Seasonal and annual rainfall projections are provided for the Rangitikei River catchment area above the scheme abstraction (MfE 2008). Table 0-38 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090.

Table 0-38 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040	2090
Summer	2	2
Autumn	3	-2
Winter	6	10
Spring	2	0
ANNUAL	3	3

Summer and autumn rainfall is projected to increase slightly by 2040. By 2090 the summer rainfall increase is the same but the autumn rainfall is projected to decrease by 2%. Winter rainfall will increase the most.

E.2.3.2 Air Temperature

Projections of changes in mean seasonal and annual temperature for the Manawatu-Wanganui region are detailed in Table 0-39 (MfE 2008).

Table 0-39 : Average Projected Change in Mean Annual and Seasonal Temperature (°C) – Lower and Upper Limits in Brackets

	2040	2090
Summer	1.1 *(0.2, 2.3)*	2.3 *(0.9, 6.0)*
Autumn	1.0 *(0.2, 2.6)*	2.2 *(0.6, 5.3)*
Winter	0.9 *(0.2, 2.2)*	2.1 *(0.5, 5.0)*
Spring	0.8 *(0.0, 1.9)*	1.8 *(0.3, 4.9)*
ANNUAL	0.9 *(0.2, 2.2)*	2.1 *(0.6, 5.3)*

Within the area served by the scheme, when compared to the current climate, it is projected that by 2040 there will around 10 more days where the temperature will exceed 25°C (MfE 2008, Mullan et al 2001). By 2090 there are projected to be 15 to 25 days more above 25°C.

Projected changes to days with frost (or days where temperature is less than 0°C) within the scheme area show a reduction of 5 days in both 2050 and 5 to 10 days by 2100 (Mullan et al 2001).

E.2.3.3 Drought

A PED of 50 to 250mm is estimated as the 20-year ARI drought event for the Rangitikei River catchment above the scheme intake. The area served by the scheme has a 20-year PED of around 400mm.

Table 0-40 details projected changes to the one in 20-year ARI PED as interpreted from Mullan et al (2005). The frequency of extreme drought increases for both the catchment area and the area served by the scheme.

Table 0-40 : Projected Frequency of Current 1 in 20-Year ARI PED Drought – Hunterville Scheme

Year	Source Catchment Area	Scheme Area
2030	10 to 15-year	15-year
2080	5 to 10-year	7 to 12-year

Projected increases in the frequency of repeat drought events have been calculated (EcoClimate 2008).

A PED drought threshold of 400mm (equal to approximately a 20-year ARI in the scheme area) currently has around a 1% chance of a repeat annual occurrence. This is projected to increase only a very minor amount to 2% by 2030 and around 4% by 2080.

E.2.3.4 Water Temperatures

Average air temperature in the Manawatu-Wanganui region area is projected to increase 0.9°C above current levels by 2040 and 2.1°C by 2090. An increase in average water temperature of rivers is also projected, but the magnitude of that change is subject to a number of factors including river base flows, water depth and the intactness of riparian vegetation.

The Rangitikei River is a large watercourse which originates in the Kaimanawa Mountains some 100km north of Hunterville. It runs through agricultural land for much of its length in a broad open channel which is too wide to be shaded by riparian vegetation. Projected increased seasonal rainfall should result in higher average river flows in winter and summer, but slightly lower autumn flows. These factors suggest that the Rangitikei River is moderately susceptible to summer heating, and that a moderate increase in peak temperatures is likely in the future.

E.2.3.5 Water Quality and Aquatic Ecology

Water is sourced from the Rangitikei River approximately 1500m downstream of the Vinegar Hill Bridge. Water is taken at a rate of up to 22L/s via an infiltration gallery located in the gravels some 3 to 4 meters below the river level. It is then pumped, in a series of lifts, to a main reservoir with a capacity of 350m^3, from where is it distributed through the scheme.

Due to the limited storage capacity the demand for irrigation water is highest during periods of dry summer weather when the river flow is low. Over the next 80 years winter and summer rainfall is projected to increase while autumn rain maybe slightly lower, and the overall the risk of drought is also projected to increase.

The Rangitikei River is expected to show a moderate increase in peak summer temperatures which, together with higher carbon dioxide levels, may increase primary production rates. For much of the time it is likely that increased rates of algae growth will be offset by an increased frequency of heavy rainfall events, which scour the river bed and remove algae biomass. However, during periods of drought algae biomass can be expected to accrue more rapidly, potentially leading to water quality effects such as increasingly variable pH and dissolved oxygen regimes. The potential consequences for the rural water supply scheme infrastructure may include increased clogging of screens and possibly increased pipe corrosion.

Much of the Rangitikei catchment is erosion prone. The projected increase in the frequency and magnitude of heavy rainfall events is likely to lead to increased sediment yields, with potential implications for the level of treatment required for water supply.

E.2.4 Malvern RWS

E.2.4.1 Rainfall

Seasonal and annual rainfall projections are provided for the Selwyn district (MfE 2008). Table 0-41 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090.

Projected changes to rainfall in the foothills that supply the Selwyn and Hawkins rivers are the same as for the area served by the scheme.

Table 0-41 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040	2090
Summer	2	3
Autumn	5	6
Winter	-8	-11
Spring	-1	-2
ANNUAL	-1	-2

The area served by the Malvern scheme is projected to see an increase in summer and autumn rainfall by 2040 and 2090. Winter and spring rainfall is projected to decrease, leading to an overall decrease in annual rainfall.

The lower winter and spring rainfall will have an effect on the Selwyn and Hawkins rivers and groundwater recharge for the source of the Malvern Hills scheme. Lower groundwater recharge could lead to lower groundwater levels and decreased availability.

E.2.4.2 Air Temperature

Projections of changes in mean seasonal and annual temperature for the Malvern Hills scheme area are detailed in Table 0-42 (MfE 2008).

Table 0-42 : Average Projected Change in Mean Annual and Seasonal Temperature (°C) – Lower and Upper Limits in Brackets

Season	2040	2090
Summer	0.9 *(0.1, 2.2)*	2.1 *(0.8, 5.2)*
Autumn	0.9 *(0.2, 2.2)*	2.1 *(0.7, 4.9)*
Winter	1.0 *(0.4, 2.0)*	2.2 *(0.8, 5.1)*
Spring	0.8 *(0.2, 1.8)*	1.8 *(0.4, 4.7)*
ANNUAL	0.9 *(0.2, 1.9)*	2.0 *(0.7, 5.0)*

In comparison to the current climate it is projected that by 2040 there will 7 to 10 more days where the temperature will exceed 25°C (MfE 2008, Mullan et al 2001). By 2090 there is projected to be 12 to 20 days more above 25°C.

Projected changes to days with frost (or days where temperature is less than 0°C) show a reduction of 10 fewer days by 2050 and 15 to 20 fewer days by 2100 (Mullan et al 2001).

E.2.4.3 Drought

A PED of 465mm is estimated as the 20-year ARI drought event for Darfield (within the scheme area).

Table 0-43 details projected changes to the 1 in 20-year ARI PED as interpreted from Mullan et al (2005). The frequency of extreme drought for the area served by scheme is expected to increase to 1 in 8 to 15-years in 2030 and 4 to 11-years in 2080.

Table 0-43 : Projected Frequency of Current 1 in 20-Year ARI PED Drought – Malvern Hills RWS

Year	Resulting ARI
2030	8 to 15-year
2080	4 to 11-year

Projected increases in the frequency of repeat drought events have been calculated (EcoClimate 2008).

A PED drought threshold of 400mm (equal to slightly less than the 20-year ARI in the scheme area) currently has around a 12% chance of a repeat annual occurrence. This is projected to increase to between 12% and 23% by 2030 and between 25% and 39% by 2080.

E.2.4.4 Groundwater

Rainfall recharge to groundwater in winter and spring is projected to decrease, particularly in winter (8% by 2040 and 11% by 2090). River flows in the Selwyn and Hawkins rivers will also be less in these months which may also affect groundwater recharge.

Summer and autumn rainfall is expected to increase which could aid in groundwater recharge and reduce water demand. However, this increase in rainfall could occur in heavy rainfall events.

E.2.4.5 Water Temperatures

Average air temperature in the Malvern Hills area is projected to increase 0.9°C above current levels by 2040 and 2.0°C by 2090. An increase in average water temperature of rivers is also projected, but the magnitude of that change is subject to a number of factors including river base flows, water depth and the intactness of riparian vegetation.

The Selwyn River is a moderately large watercourse which originates in the Big Ben and Russell Ranges. It drains an agricultural catchment which has retained little of its native vegetation cover. Riparian vegetation is retained on the river bank in places but the middle and lower river channel is too broad to be effectively shaded by vegetation. The Hawkins River is a minor tributary of the Selwyn, which also arises in the Russell Ranges and runs through an agricultural catchment. Projected increases in summer and autumn rainfall may offset potential increases in summer heating to some extent, but climate projections suggest the high rainfall may be delivered mostly in major rainfall events, with increased risk of drought at other times. These factors suggest that the both rivers are susceptible to summer heating, and that a significant increase in peak temperatures is likely in the future.

E.2.4.6 Water Quality and Aquatic Ecology

Water is sourced from the Selwyn River at Hartley Road and from the Hawkins River. Due to limited storage capacity the demand is highest during periods of dry summer weather when river flows are low. Projected increases in summer and autumn rainfall may increase average river flows over this period, however winter and spring rainfall is expected to reduce and an increased risk of drought is also projected.

Both rivers are expected to have increased peak summer temperatures which, together with higher carbon dioxide levels, may increase primary production rates. Increased rates of algae growth may be partially offset by an increased frequency of heavy rainfall events, which scour the river bed and remove algae biomass. However, during periods of drought algae biomass can be expected to accrue more rapidly, potentially leading to water quality effects such as increasingly variable pH and dissolved oxygen regimes. The potential consequences for the rural water supply scheme infrastructure may include increased clogging of screens and possibly increased pipe corrosion.

E.2.5 Rocklands RWS

E.2.5.1 Rainfall

Seasonal and annual rainfall projections are provided for the Dunedin region (MfE 2008). Table 0-44 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090.

Table 0-44 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040	2090
Summer	1	0
Autumn	2	2
Winter	3	7
Spring	2	6
ANNUAL	2	4

Overall, annual rainfall is projected to increase in Dunedin. Summer rainfall will remain similar to the current situation, while winter and spring show the largest projected increases in 2090.

E.2.5.2 Air Temperature

Projections of changes in mean seasonal and annual temperature for the Otago region are detailed in Table 0-45 (MfE 2008).

Table 0-45 : Average Projected Change in Mean Annual and Seasonal Temperature (°C) – Lower and Upper Limits in Brackets

Season	2040	2090
Summer	0.9 *(0.2, 2.4)*	2.0 *(0.7, 4.8)*
Autumn	0.9 *(0.1, 1.9)*	2.0 *(0.8, 4.6)*
Winter	1.0 *(0.3, 2.1)*	2.2 *(0.8, 4.8)*
Spring	0.7 *(0.0, 1.8)*	1.7 *(0.5, 4.3)*
ANNUAL	0.9 *(0.1, 1.9)*	2.0 *(0.8, 4.6)*

In comparison to the current climate it is projected that by 2040 there will 1 to 5 more days where the temperature will exceed 25°C (MfE 2008, Mullan et al 2001). By 2090 there is projected to be 5 to 10 days more above 25°C.

Projected changes to days with frost (or days where temperature is less than 0°C) show a reduction of 10 to 15 days by 2050 and 20 to 30 days by 2100 (Mullan et al 2001).

Storage of seasonal snow in the upper catchment area will be reduced. This will affect river flow.

E.2.5.3 Drought

A PED of 400mm is estimated as the 20-year ARI drought event for the Rocklands scheme area.

Table 0-46 details projected changes to the one in 20-year ARI PED as interpreted from Mullan et al (2005). The frequency of extreme drought is expected to increase to one in 10 to 15-years in 2030 and 5 to 10-year in 2080.

Table 0-46 : Projected Frequency of Current one in 20-Year ARI PED Drought – Rocklands RWS

Year	Resulting ARI
2030	10 to 15-year
2080	5 to 10-year

Projected increases in the frequency of repeat drought events have been calculated (EcoClimate 2008).

A PED drought threshold of 200mm currently has around a 9% chance of a repeat annual occurrence. This is projected to increase only a very minor amount to 11% by 2030 and around 15% by 2080.

E.2.5.4 River Flow

Fitzharris (2010) details runoff modelling for the neighbouring Taieri River for the current climate and that in 2040 (warming of 1°C and 5% wetter) and 2090 (warming of 2°C and 10% wetter). Mean annual runoff increases, however the seasonal distribution changes markedly with a substantial increase in autumn and winter runoff, and less summer runoff.

Similar results can be expected in the Deep Stream catchment (Fitzharris 2010), which is the water source for the Rocklands RWS.

E.2.5.5 Water Temperatures

Average air temperature in the Otago Region is projected to increase 0.9^{o}C above current levels by 2040 and 2.0^{o}C by 2090. An increase in average water temperature of rivers is also projected, but the magnitude of that change is subject to a number of factors including river base flows, water depth and the intactness of riparian vegetation.

Deep Creek is a minor upper tributary of Deep Stream which in turn is a tributary of the Taieri River. Deep Creek originates in the Lammerlaw Ranges. It drains an agricultural catchment which has retained little of its native vegetation cover. Riparian vegetation is intermittent but the creek is deeply incised and runs at high elevation. Rainfall is expected to increase in the autumn, winter and spring while little change is expected in the summer. It is therefore not particularly susceptible to summer heating and no more than a moderate increase in peak water temperature is likely in the future.

E.2.5.6 Water Quality and Aquatic Ecology

The Dunedin City Council water is sourced from Deep Creek high in the catchment. The Rocklands rural water scheme is supplied by an off take from the DCC pipeline. Due to limited storage capacity the demand for water is highest during periods of dry summer weather when the creek flow is low. Projected increases in autumn, winter and spring rainfall may increase average flows in the Deep Creek. However, no increase in summer rainfall is expected and an increased risk of drought is likely.

A projected moderate increase in peak summer water temperatures and higher carbon dioxide levels may increase primary production rates in Deep Creek. Increased rates of algae growth may be partially offset by an increased frequency of heavy rainfall events, which scour the river bed and remove algae biomass. However, during periods of drought algae biomass can be expected to accrue more rapidly, potentially leading to water quality effects such as increasingly variable pH and dissolved oxygen regimes. The potential consequences for the rural water supply scheme infrastructure may include increased clogging of screens and possibly increased pipe corrosion.

E.2.6 Homestead RWS

E.2.6.1 Rainfall

Seasonal and annual rainfall projections are provided for the Homestead scheme area (MfE 2008). Table 0-47 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090.

Table 0-47 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040	2090
Summer	1	1
Autumn	2	3
Winter	15	20
Spring	7	15
ANNUAL	5	10

The projected changes to mean annual rainfall show an increase across all seasons in the area of the Homestead scheme. Projected seasonal changes vary with small projected increases in summer and autumn, and relatively large increases in winter and spring. Winter rainfall is projected to increase significantly – up to 20% by 2090.

E.2.6.2 Air Temperature

Projections of changes in mean seasonal and annual temperature for the Homestead scheme area are detailed in Table 0-48 (MfE 2008).

Table 0-48 : Average Projected Change in Mean Annual and Seasonal Temperature (°C) – Lower and Upper Limits in Brackets

Season	2040	2090
Summer	0.9 *(0.0, 2.4)*	2.0 *(0.7, 4.7)*
Autumn	0.9 *(0.1, 1.9)*	2.0 *(0.8, 4.6)*
Winter	1.0 *(0.2, 2.0)*	2.2 *(0.8, 4.7)*
Spring	0.7 *(-0.1, 1.7)*	1.6 *(0.5, 4.1)*
ANNUAL	0.8 *(0.1, 1.9)*	1.9 *(0.8, 4.5)*

In comparison to the current climate it is projected that by 2040 there will be up to 5 more days where the temperature will exceed 25°C (MfE 2008, Mullan et al 2001). By 2090 there is projected to be 5 to 10 days more above 25°C.

Projected changes to days with frost (or days where temperature is less than 0°C) show a reduction of 10 to 15 days by 2050 and up to 20 days by 2100 (Mullan et al 2001).

E.2.6.3 Drought

A PED of 300mm is estimated as the 20-year ARI drought event for the Homestead scheme area.

Table 0-49 details projected changes to the one in 20-year ARI PED as interpreted from Mullan et al (2005).

Table 0-49 : Projected Frequency of Current one in 20-Year ARI PED Drought – Homestead RWS

Year	Resulting ARI
2030	10 to 20-year
2080	15 to 20-year

Projected increases in the frequency of repeat drought events have been calculated (EcoClimate 2008).

A PED drought threshold of 200mm currently has around a 3% chance of a repeat annual occurrence. This is projected to decrease to 2% by 2030 and return upwards to 3% by 2080.

E.2.6.4 Water Temperatures

Average air temperature in the Te Anau area is projected to increase 0.8°C above current levels by 2040 and 1.9°C by 2090. An increase in average water temperature of rivers is also projected, but the magnitude of that change is subject to a number of factors including river base flows, water depth and the intactness of riparian vegetation.

The Whitestone River is a tributary of the Mararoa River which in turn is a tributary of the Waiau River. The Whitestone originates at the southern end of the Livingston Range. The upper catchment is alpine grading down to subalpine forest, while the middle and lower catchment is predominantly agricultural. Riparian vegetation becomes sparse and intermittent in the middle and lower catchment and the river channel is wide and mostly unshaded. Rainfall is expected to progressively increase over the next 80 years, with the strongest increase (up to 20%) occurring in the winter and spring. The Whitestone River is considered to be not particularly susceptible to summer heating and only a moderate increase in peak water temperature is likely in the medium term.

E.2.6.5 Water Quality and Aquatic Ecology

Water is sourced from shallow bores adjacent to the Whitestone River approximately 4km upstream of SH 94. Due to limited storage capacity the demand for water is highest during periods of dry summer weather when the river flow is low. Projected increases in autumn, winter and spring rainfall will increase average river flows, although only a minor increase is projected for summer. On balance the availability of water during the summer period is unlikely to be markedly different from current levels.

Didymo is well established in the Whitestone River, covering much of the riverbed at some locations (Kilroy et al 2007), and may already have increased costs for maintenance of the rural water supply scheme. A projected moderate increase in peak summer water temperatures and higher carbon dioxide levels may increase primary production rates in the Whitestone River. However, increased rates of algae growth may be partially offset by an increased frequency of heavy rainfall events, which scour the river bed and remove algae biomass.

E.2.7 Wainuioru RWS

E.2.7.1 Rainfall

Seasonal and annual rainfall projections are provided for Masterton, immediately to the west of the Wainuioru scheme (MfE 2008). Table 0-50 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090.

Table 0-50 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040	2090
Summer	2 (-17, 25)	4 (-28, 32)
Autumn	4 (-8, 32)	3 (7, 13)
Winter	-6 (-20, 4)	-7 (-28, 2)
Spring	-1 (-8, 10)	-4 (-20, 16)
ANNUAL	-1 (-7, 9)	-2 (-15, 7)

Summer and autumn rainfall is projected to increase slightly, although the upper and lower limits for summer range from a large negative to a large positive change.

Long term rainfall trends show a clear decline in rainfall around the scheme area since 1983 (M Gyopari, pers. comm. 2010). Annual rainfall is projected to decrease overall due to climate change (Table 0-50) so this trend may continue.

E.2.7.2 Air Temperature

Projections of changes in mean seasonal and annual temperature for the Masterton area are detailed in Table 0-51 (MfE 2008).

Table 0-51 : Average Projected Change in Mean Annual and Seasonal Temperature (°C) – Lower and Upper Limits in Brackets

Season	2040	2090
Summer	1.0 *(0.2, 2.2)*	2.2 *(0.9, 5.7)*
Autumn	1.0 *(0.3, 2.5)*	2.1 *(0.6, 5.1)*
Winter	0.9 *(0.2, 2.1)*	2.1 *(0.6, 5.0)*
Spring	0.8 *(0.1, 1.9)*	1.8 *(0.3, 4.8)*
ANNUAL	0.9 *(0.3, 2.2)*	2.1 *(0.6, 5.2)*

In comparison to the current climate it is projected that by 2040 there will around 10 more days per annum where the temperature will exceed 25°C (MfE 2008, Mullan et al 2001). By 2090 there are projected to be 20 to 30 days more above 25°C. Projections for number of days where the temperature will exceed 30°C show an increase of 1 to 3 days per year by 2050, and an increase of 3 to 7 days by 2100.

Projected changes to days with frost (or days where temperature is less than 0°C) show a reduction of 5 to 10 days by 2050 and a reduction of 10 to 20 days by 2100 (Mullan et al 2001).

E.2.7.3 Drought

A PED of around 500mm is the 20-year ARI drought event for the scheme area.

Table 0-52 details projected changes to the 1 in 20-year ARI PED as interpreted from Mullan et al (2005). The frequency of extreme drought for the area served by scheme increases to between 1 in 5 to 15-years in 2030 and 2.5 to 15-year in 2080.

Table 0-52 Projected Frequency of Current one in 20-Year ARI PED Drought – Wainuioru RWS

Year	Resulting ARI
2030	5 to 15-year
2080	2.5 to 15-year

E.2.7.4 Groundwater Levels

Groundwater levels in the Te Ore Ore area (in which the Wainuioru scheme is located) show a long term trend of decline since records began in 1983. This can be attributed to a trend of decreasing rainfall

(Section E.2.7.1) and an increasing trend of abstraction from the groundwater source since the mid 1990s (M Gyopari pers. comm., 2010).

Groundwater in the area is recharged by a combination of rainfall and input from the Ruamahanga River.

E.2.8 Redwoods RWS

E.2.8.1 Rainfall

Seasonal and annual rainfall projections are provided for the Tasman region (MfE 2008). Table 0-53 details the projected percentage changes in seasonal and annual rainfall expected in 2040 and 2090.

Table 0-53 : Percentage Change in Mean Annual and Seasonal Rainfall (MfE 2008)

Season	2040	2090
Summer	4	6
Autumn	5	5
Winter	1	6
Spring	0	-1
ANNUAL	2	4

Annual rainfall is projected to increase by 2040 and 2090. Summer and autumn rainfall shows increases of 4-5% by 2040 and 5-6% by 2090 are expected.

A report by TDC (2005) states that although the source aquifer for the scheme is fully allocated, there is the possibility of future development and increased pressure on the water supply. Possible increases to the summer and autumn rainfall could help to reduce demand on the resource, although this increase could likely occur during heavy rainfall events.

Winter and spring rainfall recharge to the aquifer is projected to be largely unchanged to 2040. By 2090 there could be a 6% increase in winter rainfall and a 1% decreases in spring rainfall.

E.2.8.2 Heavy Rainfall Events

An increase in the size and/or frequency of large flood events coupled with projected rises in sea level raises the risk of inundation during floods to some properties within the scheme near the Waimea Inlet. Flood levels could be higher and breach existing flood defences if sea level rise occurs.

E.2.8.3 Air Temperature

Projections of changes in mean seasonal and annual temperature for the Tasman region are detailed in Table 0-54 (MfE 2008).

Table 0-54 : Average Projected Change in Mean Annual and Seasonal Temperature (°C) – Lower and Upper Limits in Brackets

Season	2040	2090
Summer	1.0 *(0.2, 2.2)*	2.2 *(0.9, 5.6)*
Autumn	1.0 *(0.2, 2.3)*	2.1 *(0.6, 5.1)*
Winter	0.9 *(0.2, 2.0)*	2.0 *(0.5, 4.9)*
Spring	0.7 *(0.1, 1.8)*	1.7 *(0.3, 4.6)*
ANNUAL	0.9 *(0.2, 2.0)*	2.0 *(0.6, 5.0)*

In comparison to the current climate it is projected that by 2040 there will 10 to 15 more days where the temperature will exceed 25°C (MfE 2008, Mullan et al 2001). By 2090 there are projected to be 15 to 35 days more above 25°C.

Projected changes to days with frost (or days where temperature is less than 0°C) show a reduction of 5 to 10 days in by 2050 and a reduction of 10 to 20 days by 2100 (Mullan et al 2001).

E.2.8.4 Drought

A PED of 600mm is estimated as the 20-year ARI drought event respectively for the Redwoods scheme area.

Table 0-55 details projected changes to the 1 in 20-year ARI PED as interpreted from Mullan et al (2005). The frequency of extreme drought is expected to change for the area to between a 5 and 15-year ARI by 2030 and between a 5 and 10-year ARI by 2080.

Table 0-55 : Projected Frequency of Current 1 in 20-Year ARI PED Drought – Redwoods RWS

Year	Resulting ARI
2030	5 to 15-year
2080	5 to 10-year

Despite the projected increase in mean rainfall, drought conditions are expected to become worse.

E.2.8.5 Groundwater

A base mean sea level rise of 0.5m by 2090 has been put forward by NIWA (MfE 2008). A worst case scenario of a 1.9m sea level rise has been suggested by Goodwin (2009). Sea level rise would impact on the groundwater and saltwater interface of the aquifer from which the scheme water supply is obtained. The risk of saltwater intrusion will increase.

Appendix F: Industry Bodies

F.1 Irrigation New Zealand

Irrigation New Zealand (INZ) was formed in 1999 to promote excellence in irrigation development and efficient water management throughout New Zealand, based on the principles of responsible and sustainable management of water (INZ website June 2010).

INZ focus is to:
- Influence national and local policymakers to ensure outcomes are equitable, practical and accountable for irrigation
- Drive the development and uptake of irrigation best management practice
- Encourage the development and regulatory acceptance and implementation of self management systems for irrigators
- Create technical standards and associated learning pathways for the NZ irrigation industry
- Foster and promote innovative irrigation research
- Develop linkages between INZ, the NZ primary sector and sister irrigation organisations overseas
- Improve community understanding and acceptance of the benefits of irrigation.

INZ incorporates a Technology and Trade special interest Group (INZT&T) that was developed to:

- Drive the production and uptake of industry standards and associated training
- Provide technical information to feed into the INZ advocacy and leadership activities
- Act as a voice for the industry technical sector.

The following list was established by INZ as a preliminary set of focus areas for further projects for study by the INZT&T:

- Marketing of the benefits of irrigated agriculture – a collaborative approach to heighten awareness of the link to the wider community in terms of economic, social, cultural and environmental indicators.
- Engineering improvements and challenges – a wide variety of areas can still be developed further. These will include
  - Water storage
  - Fish screen design and implementation
  - Back flow preventers and fertigation
  - Water meter installation standards for NZ
  - Irrigation system design parameters relative to production
  - Dairy effluent disposal technology and management
  - Energy efficiency of pumps
  - Soil moisture and climate monitoring practices
- Education on irrigation technology and water resource management for farmers, the wider community, regulators and lenders.

F.2 New Zealand Society of Large Dams (NZSOLD)

The *New Zealand Society on Large Dams* (NZSOLD) was founded to advance the technology of dam engineering and support socially and environmentally responsible development and management of water resources (NZSOLD worksite, 2010).

The objectives of the Society are:

- To promote best practice in the development, operation, maintenance and refurbishment of dams and their associated impoundments throughout New Zealand
- To integrate best practice into the regulatory process associated with the dam and impoundment management industry in New Zealand
- To be recognized as a credible and respected professional body, and the national focus for all matters relating to dams and their associated impoundments in New Zealand.

NZSOLD aim to accomplish this by:

- Fostering cooperation
- Promoting the adoption of regulatory policies and safety guidelines for dams and reservoirs throughout New Zealand
- Providing information and assistance to dam owners in support of dam safety programs;
- Sharing information with New Zealand and international organisations interested in dam safety.

Appendix G: Irrigation Infrastructure Susceptibility to Climate Change

G.1 Irrigation Schemes

An inventory of irrigation scheme infrastructure assets has been prepared as detailed in Table G-1, and a quantitative "traffic" light ranking of its susceptibility to the impacts of climate change prepared. This categorisation has been prepared to convey the findings of this study, informal observations from the study, or internal knowledge of MWH staff.

The table is presented in a format that can be used by existing scheme operators and potential scheme developers to consider the impacts of climate change on various components without repeating this study. The table is generic and scheme specific use of this information should be taken as a guide only.

The base source of Table G-1 is the *NZ Infrastructure Asset Valuations and Depreciation Guidelines – Version 2.0, 2006, Section 5.3.* Additions to this table have been made to reflect our assessment of the impacts on irrigation scheme assets and their susceptibility to climate change.

The *NZ Infrastructure Asset Valuation and Depreciation Guideline – Version 2.0, Section 4.6*, details the sectors that can be used for determining the useful life of assets, and this methodology can be adopted for an assessment of climate change impacts on irrigation infrastructure. The impacts of climate change can be considered as an Asset Working Environment Factor 6 of Table 4.6.3 in the Guideline, and the impacts transferred through to step 3 to evaluate the total physical life of an asset. If this technique (not reported in this study) were undertaken for a design with and without the impacts of climate change, then the full impacts of climate change can be readily determined for any scheme or project.

G.2 Typical Useful Lives for Infrastructure

Table G-1 schedules typical base lives adopted for water utility infrastructure valuations prepared for New Zealand Local Authorities. Irrigation schemes typically operate to a less conservative useful life than local authorities. Notwithstanding this, the useful lives of assets presented are considered appropriate for an impacts assessment.

G.2.1 Pipe Network Assets

There is considerable debate on the appropriate useful service life of pipes because in many cases they are of relatively young age compared to their expected life, or because age and material data is inadequate to analyse the failure patterns.

In determining a standard useful life or an acceptable range for pipes the following matters need to be considered:

- Technical properties for pipes (e.g. asbestos cement, polyethylene, PVC, ABS);
- History with regard to pipe performance and renewal;
- Type of back fill (which alters load point pressure);
- Ground conditions;
- Methods used to join pipes (e.g. rubber ring, mortar, solvent welding, electro-fusion) which alter the life expectancy;
- Pipe protection techniques used (e.g. plastic coating, cathodic protection);
- Methods of renewing pipes (directional drilling, insertion, open cut);
- Operating practices regarding the replacement of pipes for safety, product loss or maintenance reasons;
- Historical maintenance practices; and
- Change in weed or sediment ingestion and subsequent erosion patterns.

G.2.2 Canal or Dam Network Assets

Canals themselves are usually constructed in excavated ground, and have long life spans. Canals typically have a number of other assets integrated into then such as:

- Cross culverts for stormwater canal
- Fill embankment sections
- Drop structures
- Farm or road crossings
- Gate and control structures
- Pumps or gates
- Canal distribution structures.

In determining a standard useful life for canal structures the following matters need to be considered:

- Geology of canal area
- Soil engineering properties
- Stability of ground
- Ground conditioning
- Aggressiveness of surface water
- Construction techniques
- Infrastructure material types
- Operating practices
- Historic maintenance practices
- Weed and sediment management practices.

G.2.3 Electrical and Mechanical Equipment

Useful lives can be assigned to pump assemblies based either on the physical life of the set or on the period of time between major refurbishment of components.

Technological change will be a significant factor for electrical equipment such as SCADA.

One particular issue with pumps is that historical management practice may have been to refurbish and maintain for long periods of time and not capitalise the refurbishment. However, with reducing pump replacement costs compared to refurbishment costs, it is now possible to replace on a 10 or 15 year cycle in the future. In this case the life of the existing asset should be used (which may be 20 or 30 years) but when the pump is replaced the useful life of the replacement should be set to reflect current renewal practice.

G.2.4 Structures (Inlets, Screens, Gates)

Significantly longer useful lives can be adopted where performance issues are not a factor and either the design incorporates corrosion retardation features (e.g. cathodic protection, protective coatings) or intensive maintenance regimes prolong the life of the asset.

Table G-1: Susceptibility of Irrigation Scheme Infrastructure Assets to Climate Change

Asset Group	Asset Type	Component	Typical Useful Lives (Years)	Susceptibility to Climate Change
Irrigation Infrastructure				
Piped Reticulation	Pumped Trunk Mains	Pipes	20-150	🟠
		Line valves	25-75	🔴
		Hydrant	25-75	🟠
		Scour valves	25-75	🟢
		Meters	10-35	🟠
	Pumped Mains	Pipes	50-150	🟠
		Line valves	25-150	🔴
		Scour valves	25-150	🟢
		Meters	10-35	🟠
	Pumped Service Lines	Pipes	50-100	🟠
		Line vales	25-100	🔴
		Meters	10-35	🟠
Pump Stations	Pump Station	Structure – wet wells	50-100	🟠
		Structure – pump house	35-100	🟢
		Electrical Control Equipment	15-35	🟢
		Telemetry	10-25	🟢
		Pumps	10-35	🔴
		Valves	10-35	🔴
		Meters	10-25	🟠
		Pipe-work	15-35	🟠
Canals	Open Channels	Channel	60-100	🟢
		Channel lining	20-75	🔴
		Control structure	50-100	🟠
		Drop structure		🟢
		Culverts		🟢
		Offtake gates		🟢

Asset Group	Asset Type	Component	Typical Useful Lives (Years)	Susceptibility to Climate Change
Irrigation Infrastructure				
Headworks	Intake System	Sediment ponds		🔴
		Pipes/barrel	50-75	🟢
		Inlet/outlet structure	75-100	🟢
		Screens	10-35	🔴
		Mechanical cleaners	10-35	🔴
	Bores	Bore casing	10-75	🟢
		Screen	25-75	🟢
		Pumps	12-35	🔴
		Electrical Control	15-35	🟢
		Telemetry	10-25	🟢
Storage	Reservoirs (tanks)	Main Structure	40-100	🟢
		Valves	20-100	🟢
		Meters	10-25	🟠
		Pipe-work, intakes, screens	15-100	🔴
		Telemetry	10-25	🟢
	Dams, Canals and Tunnels	Structure	75-100	🟠
		Spillway	75-100	🔴
		Mechanical controls	50-100	🟠
		Electrical controls	15-30	🟢
		Tunnels	75-100	🟢